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VLOGA KONDENZNE KOROZIJE V TERMALNI SPELEOGENEZI: ŠTUDIJA HIPOGENE SULFIDNE JAME V AIX-LES-BAINS, FRANCIJA

Philippe AUDRA[1], Fabien HOBLEA[2], Jean-Yves BIGOT[3] & Jean-Claude NOBECOURT[4]

Abstract UDC 551.435.8:551.3.053(44)

Philippe Audra, Fabien Hoblea, Jean-Yves Bigot & Jean-Claude Nobecourt: The role of condensation corrosion in thermal speleogenesis. Study of a hypogenic sulfidic cave in Aix-les-Bains, France

Condensation-corrosion is an active speleogenetical process in thermal caves where high thermal gradient drives air convection. Wall retreat rates are greater than in meteoric caves. Conversely, evaporation produces depositional processes by replacement of limestone by gypsum and by aerosol decantation leading to the formation of popcorns. The Chevalley Aven belongs to Aix-les-Bains thermal-sulfidic cave system. Condensation occurs at the contact of cool walls of large spheres; conversely, evaporation occurs at the output of the narrow passages where the air sinks down from the upper sphere. A weathered layer and biofilms are present where slow condensation occurs. Corrosion distribution varies according to thermal rock conductivity and causes the sphere to develop upwards, laterally, and divergent. This morphodynamic pattern favors the development of stacked spheres, isolated by narrow necks, and arranged in a bush-like pattern. This development is clearly active in the vadose zone above the thermal water table. We propose that some avens above water table hypogenic caves, like Villa Luz (Mexico), may be of condensation-corrosion origin instead of phreatic. Future development will collect physical and chemical data to calculate the condensation-corrosion budget and assess its role in cave development.

Key words: condensation-corrosion, thermal caves, sphere genesis, air convection, Aix-les-Bains thermal-sulfidic cave system, Chevalley Aven, France.

Izvleček UDK 551.435.8:551.3.053(44)

Philippe Audra, Fabien Hoblea, Jean-Yves Bigot & Jean-Claude Nobecourt: Vloga kondenzne korozije v termalni speleogenezi: študija hipogene sulfidne jame v Aix-les-Bains, Francija

Kondenzacijska korozija predstavlja aktivni speleogenetski proces v termalnih jamah, kjer kroženje zraka povzroča visok termalni gradient. Raztapljanje jamskih sten in stropa je v takšnih jamah večje, kot v vodnih jamah. Izhlapevanje povzroča tudi odlaganje, ki se vrši v obliki nadomeščanja apnenca s sadro in z usedanjem aerosola, kar vodi v tvorbo značilnih morfoloških oblik (popcorn). Brezno Chevalley sodi k termalno-sulfidnemu jamskemu sistemu Aix-les-Bains. Kondenzacija deluje na stiku toplega zraka s hladnimi jamskimi stenami, do izhlapevanja pa prihaja na izhodu ozkih jamskih prehodov. Prepereli sloji kamnine in prevleke biološkega izvora se pojavljajo na mestih, kjer je počasna kondenzacija. Porazdelitev korozijskega delovanja je odvisna od termalne prevodnosti kamnine in povzroča nastanek stropnih, stenskih in divergentnih krožnih oblik. Takšni morfodinamični vzorci omogočajo oblikovanje raznih kupol, ločenih z ožinami in vejasto razvrščenimi. Takšne morfološke oblike so značilne za vadozno cono. Nekatere zožitve nad vodno gladino v hipogenih jamah (npr. Villa Luz v Mehiki) so kondenzacijsko-korozijskega in ne freatičnega nastanka. Prihodnje raziskave fizikalno-kemičnih lastnosti bodo pokazale pomen vpliva kondenzacijsko-korozijskih procesov za razvoj jam.

Ključne besede: kondenzacijska korozija, termalne jame, sphere genesis, zračna cirkulacija, Aix-les-Bains thermalno-sulfidni jamski sistem, brezno Chevalley, Francija.

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INTRODUCTION

Convection and condensation-corrosion are generally considered as minor processes for cave development, producing only etching or smoothing of flow-induced features and conduits. However, some authors have put forward the importance of condensation-corrosion in specific conditions. Müller (1974) was among the first to relate spherical cupolas (called spheres in this paper) to air convection above thermal lakes, whereas Rudnicki (1978) had attributed them mainly to phreatic convection. Sphere development by condensation has been simulated numerically, focusing on the role of pressure changes connected to flooding in the epiphreatic zone (Mucke & al., 1983; Lismonde, 2000) or cooling of rising air above thermal lakes (Cigna & Forti, 1986; Szunyogh, 1990; Lismonde, 2003). Dublyansky & Dublyansky (2000) updated a review of worldwide contributions about condensation. Finally, Dreybrodt & al. (2005) recently performed a comprehensive modeling of this process within various boundary conditions. As a rule, most of these authors stated the efficiency of convection-condensation on speleogenesis only in specific conditions that are not widespread in meteoric caves, but more frequent in hypogenic caves such as thermal caves or caves with high carbonic or sulfidic atmospheres.

The study of Chevalley and Serpents Caves in Aix-les-Bains, France, clearly shows the importance of this process which is enhanced by sulfidic corrosion. Aix-les-Bains Caves, located in the Northern French Prealpes in Savoy, are still active and provide an outstanding picture of convection processes and related corrosion and deposition phenomena, particularly with gypsum replacement.

This paper presents the first results of a study of the morphology of the cave, the distribution of the deposits, and the distribution of condensation and evaporation zones, in order to make an assessment of the role of condensation-corrosion role in cave development. A second study is being undertaken to calculate the condensation-corrosion budget through the collection of physical and chemical data. The first part of this paper summarizes current knowledge about condensation-corrosion and the development of spheres. The second part examines condensation-corrosion and the resulting morphologies and deposits in Chevalley and Serpents Caves. Finally, we will discuss the respective role of the different speleogenetical processes.

CONDENSATION-CORROSION AND THE DEVELOPMENT OF SPHERES

SPELEOGENESIS BY SULFUR RELEASE AND SULFIDIC CAVES

Hypogenic caves formed from sulfur release producing sulfuric acid and limestone corrosion with replacement by gypsum were only recently identified (Morehouse, 1968; Egemeier, 1981). They have been particularly studied in the Guadalupe Mountains, USA (Hill, 1987), in the Frasassi Caves, Italy (Galdenzi & Menichetti, 1990; Forti, 1996), and in France (Audra & al., 2002; Audra & Hofmann, 2004; Audra & Häuselmann, 2004; Audra, 2005). The active participation of microbial processes was identified in Movile Cave, Romania (Sarbu & al., 1996), and in Villa Luz Cave, Mexico (Hose & Pisarowicz, 1999).

CONVECTION ABOVE A THERMAL LAKE

Air convection occurs when a thermal gradient exists between a lake heated by thermal flow and the upper part of the cave which is cooler. Evaporation from the thermal lake produces warm-moist air that rises, while cooler air sinks. Since the thermal gradient is maintained by heat transfer through the cooler rock mass toward the surface (Lismonde, 2003), permanent convection cells exchange heat and water between the different parts of the cave. The thermal flux is independent of the distance to the surface (Dreybrodt & al., 2005), but high gradients may be present close to topographic surfaces where meteoric seepage can cool the cave roof.

CONDENSATION ON COOL WALLS

Warm-moist rising air cools at the contact of the colder walls and ceilings producing condensation. Condensation, in turn, releases heat at the wall surface that lowers the thermal gradient itself (Dreybrodt & al., 2005). For vapor-saturated air, the condensation rate depends on the thermal gradient. Thus, maximal condensation rates appear when hot thermal water is present within a cave close to the surface, at the ceiling of the upper passages, and more generally in chambers which are relatively isolated by narrow passages from lowermost warmer places.

CORROSION OF THE ROCK WALLS

When condensation water quickly reaches equilibrium with carbon dioxide-rich cave atmosphere and residence time of contact between aggressive condensation water and limestone wall is sufficient, corrosion can occur (Dreybrodt & al., 2005). Such weathering of walls has been demonstrated in Movile Cave, Romania, where soft residue displays C-light isotopic ratios. This depleted carbon results from the solution of biogenic carbon dioxide (Sarbu & Lascu, 1997). Modeling of wall retreat within thermal conditions shows rates about one order of magnitude above those of meteoric karst, ranging from 2 to 20 cm / ka (Mucke & al., 1983; Cigna & Forti, 1986; Dreybrodt & al., 2005), thus allowing the possibility of cave development in a "reasonable" time-span. Modeling has also shown that in "normal" meteoric caves condensation-corrosion does not reach sufficient rates to be considered as a main speleogenetic process.

Consequently, condensation-corrosion represents a main process only in the following cases: 1/ when warm-moist air condenses in the entrance of a cold cave in summer; 2/ above thermal lakes where the thermal gradient is high; 3/ where CO_2 or H_2S-rich atmosphere gives a high aggressivity to the condensed water, even if this parameter is considerably less important than the condensation itself (Szunyogh, 1990). Condition 2 may combine with 3.

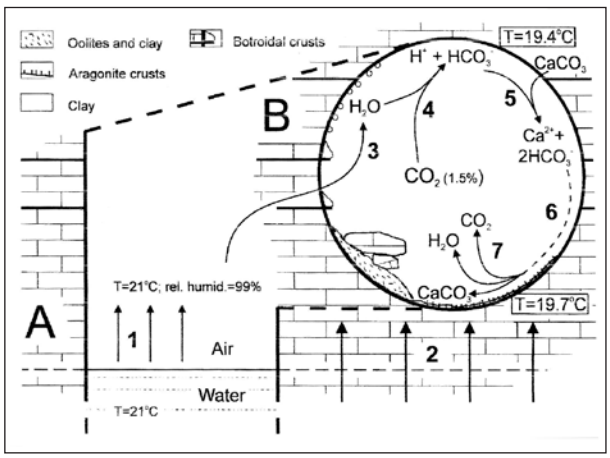


Fig. 1: Schematic profile view of Movile Cave (Sarbu & Lascu, 1997).

A. Lower passage; B. Upper dry passage

1. Evaporation of water at the surface of the lake

2. Thermal flux through the bedrock

3. Condensation of water vapor onto the colder cave walls and ceiling in the upper cave passage

4. Dissolution of CO_2 into the condensate and formation of carbonic acid.

5. Reaction between carbonic acid and the carbonate bedrock with formation of bicarbonate

6. Transport of bicarbonate along the walls

7. Precipitation of aragonite crusts and dissociation of bicarbonate

DEPOSITIONAL PROCESSES

Several types of depositional processes may occur separately or in combination: 1/ by evaporation of the condensed water at the base of walls where air is warmer; 2/ by replacement of limestone by gypsum when H_2S is released from thermal lakes; 3/ by decantation of aerosols building popcorns in the lowest part of passages (Dublyansky & Pashenko, 1997). Fig. 1 resumes the steps involved in condensation-corrosion.

SPHERE GENESIS BY CONVECTION AND CONDENSATION

The term sphere roughly corresponds to hemispheric or semi-spherical holes located in the ceiling. Spheres may develop by different processes, involving convection and sometimes additionally condensation: 1/ by pressure rise and condensation after flooding in the epiphreatic zone (Mucke & al., 1983; Lismonde, 1999); 2/ by mixing-corrosion in the phreatic zone (Bögli, 1964, 1978); 3/ by convection of water in the phreatic zone (Rudnicki, 1978); 4/ by air convection above thermal lakes (Müller, 1974; Szunyogh, 1990). Except for (1), these processes correspond to slow moving fluid (water or gas) and convection more or less directly connected to uprising water, conditions encountered more frequently in hypogenic cave systems (Osborne, 2004). We will initially consider step (4) alone, that is air convection above thermal lakes making almost perfect spheres.

The thermal conductivity of rock produces higher thermal gradients at the top of ceiling holes (Cigna & Forti, 1986; Szunyogh, 1990), thereby creating the great-

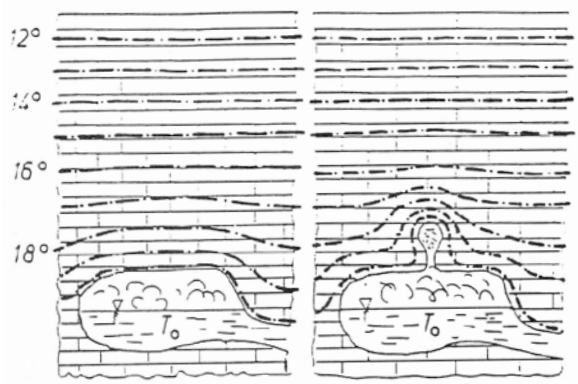
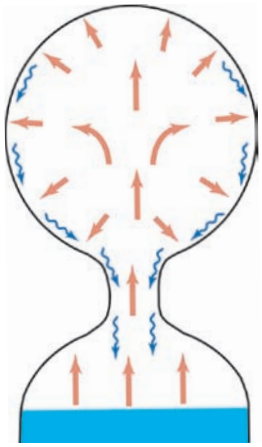


Fig. 2: Development of a sphere in the ceiling, where thermal gradient is the highest, by condensation-corrosion (Szunyogh, 1982).



est condensation and thus strongest corrosion: the sphere continues developing upward, where condensation is at the maximum, and laterally, where seepage occurs, since it is connected to the lower conduit by a narrow neck (Fig. 2, 3). Modeling shows that irregularity of the ceiling produces a new sphere development that fits within the previous one (Szunyogh, 1990). The development of two neighboring spheres will be divergent, toward the greatest potential heat transfer, because the rock in between the two spheres has less transfer potential and remains warm (Fig. 4). Such a process explains the development of stacked up spheres arranged in a bush-like structure, as found in the Sátorkö-puszta Cave, Hungary (Fig. 5). The smooth ceiling results from the regular corrosion by a thin film of condensed water rather than discrete drips (Mucke & al., 1983); slow runoff of condensed water at the base of the sphere makes corrosion furrows, and calcite deposits as popcorn at the outlet of the sphere after evaporation (Cigna & Forti, 1986).

Fig. 3: Condensation occurs at the ceiling. Wall benefits from both condensation plus seepage. Evaporation plus saturated runoff occur at the bottom, thus preventing the expansion of the neck (from Szunyogh, 1990, redrawn).

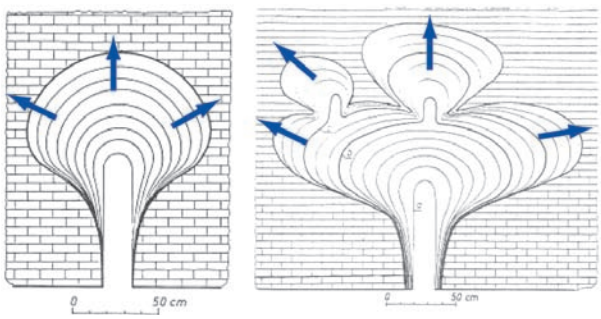


Fig. 4: Theoretical development of simple and complex spheres. Simple sphere develops upwards and laterally (left); an irregularity in the ceiling produces a new sphere development that fits within the previous one (right); two neighboring spheres diverge toward the greatest zone of heat transfer (right) (after Szunyogh, 1990, modified).

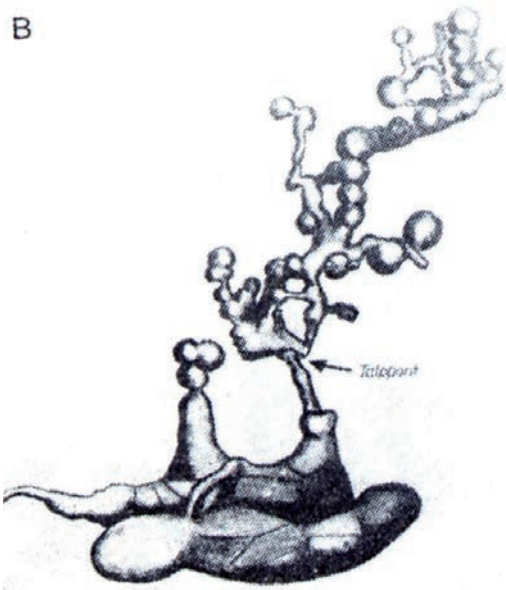


Fig. 5: 3D view of Sátorkö-puszta Cave, the bush-like pattern cave type, made of stacked up spheres (Müller & Sarvary, 1977).

AIX-LES-BAINS THERMAL-SULFIDIC CAVES (CHEVALLEY AVEN AND SERPENTS CAVE)

BUSH-LIKE SPHERES AND WATER TABLE PATTERN

Aix-les-Bains is a thermal resort in Savoy, located between the Bourget Lake shore and the foot of the Bauges massif in Northern French Prealps. Chevalley Aven and Serpents Cave belong to the same system (Fig. 6) (Hobléa, 1999; Gallino 2006). Chevalley Aven is made of stacked spheres arranged in a bush-like pattern (Sátorkö-puszta Cave type). Chevalley Aven rises from the thermal water table and does not break through the surface, and the present entrance is artificial. Serpents Cave is a water table cave, with spheres and avens at the ceiling. The active Alum thermal spring flows into the cave at the upstream end. The gallery is gently sloping downstream and is plugged at the end with till.

A SULFIDIC AND THERMAL UPWELLING FLOW

The discharge of the Alum spring ranges from 8 to 42 Ls^{-1}; the temperature oscillates seasonally between 33.5 and

46.6 °C on account of some mixing with meteoric component (Muralt, 2003). Water has a high concentration of calcium, sulfate, and secondary sodium, magnesium, and silica (Tab. 1). It degasses some H_2S and CO_2 and brings up microbial soft flakes. The temperature, high silica and salt content, and the presence of trace elements suggest a deep artesian flowpath (about 2000 m), confined under the Bourget Lake syncline, where Triassic evaporites are leached (Carfantan & al., 1998).

H_2S degassing seems less strong in Chevalley Aven, probably due to the standing water. On the contrary, the water flowing turbulently out from the Alum spring produces a stronger degassing, as is evidenced by the characteristic rotten egg smell, together with a thick coating of replacement gypsum and native sulfur covering walls around the spring pool (Audra *et. al.*, 2007). Martel (1935) was the first to identify the sulfidic origin of Serpents Cave.

THE CONVECTION CELLS IN CHEVALLEY AVEN (Fig. 7)

The aerial thermal gradient, between the pool at about 32 to 34 °C and the top of Chevalley Aven at 26 °C ranges from 0.2 to 0.3 °C/m, so, air convection cells occur. The distribution of air loops is controlled by the presence in the main passage of a cool dripping originating from both condensation and seepage. The cool airflow sinks into the main passage whereas the warm airflow rises from the thermal pool through lateral passages. The highest airflow velocity is about 15 cm/s in the narrow passages. Before 1996, water seepage originated from natural rainwater percolation through the soil. Since the building of the thermal Spa, seepage originates from leakage from the thermal pool. We present here the observations made in the small vent connecting the Lower Gallery and the Aixinoise gallery (Fig. 7). Preliminary measures were done the 10/26/2006 using a heated wire anemometer (Testo V1) which includes a digital thermometer. Device accuracy is 1 cm/s for air velocity and 0.1 °C for air temperature.

Physico-chemistry	*Values*	*Reference, if other than Muralt (2003)*
Temperature	33,5 – 46,6 °C	
Discharge	8 - 42 $L.s^{-1}$	
Conductivity	576 – 691 $\mu S.cm^{-1}$	Hobléa, 1999
pH	6,5	Hobléa, 1999
TDS	496 $mg.L^{-1}$	
$HCO3^-$	262 $mg.L^{-1}$	
$SO4^{--}$	60 - 230 $mg.L^{-1}$	
Cl^-	15 - 30 $mg.L^{-1}$	
Na^+	20 - 40 $mg.L^{-1}$	
Ca^{++}	100 - 150 $mg.L^{-1}$	
K^+	3 - 6 $mg.L^{-1}$	
Mg^{++}	10 - 25 $mg.L^{-1}$	
SiO_2	22 - 26 $mg.L^{-1}$	
H_2S	5 $mg.L^{-1}$	Iundt & al., 1987
Trace elements	Al, Fe, Mn, Pb, B, Sr, Sn, Sb, Ba, Li	Iundt & al., 1987

Tab. 1: Main physical and chemical data from the Alum spring, Serpents Cave, Aix-les-Bains (main data after Muralt, 2003).

STUDY OF CONDENSATION-CORROSION AND EVAPORATION-DEPOSITION PROCESSES OCCURRING INTO THE VENT (Fig. 8)

This vent is a narrow inaccessible passage about 3 m long. Temperature is 32.7 °C at the base, and 28.4 °C at the upper mouth. The air flow velocity is very low, about 1 cm/s or less. Warm air rises up through the vent and some sinking secondary loops appear at the contact of the cooler lateral walls of the central sphere. The accumulation of condensation produces runoff as a film along the sphere walls and dripping at the tip of downfacing pendants. Airflow is considered close to saturation regarding moisture. Consequently, cooling from rising air produces condensation in the narrow fissures, at

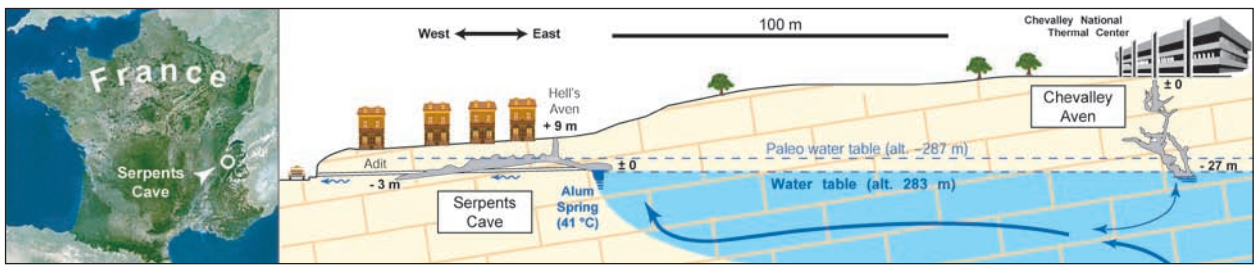


Fig. 6: Outline of Chevalley Aven and Serpents Cave, cross-section view (survey SC Savoy, EDYTEM). Serpents Cave is a water table cave, with spheres and avens at the ceiling. The active Alum thermal spring flows into the cave at the upstream end. Chevalley Aven is made of stacked up spheres arranged in a bush-like pattern and reaches the thermal water table. The "paleowater table" corresponds to the water level before the digging of the adit in 1859.

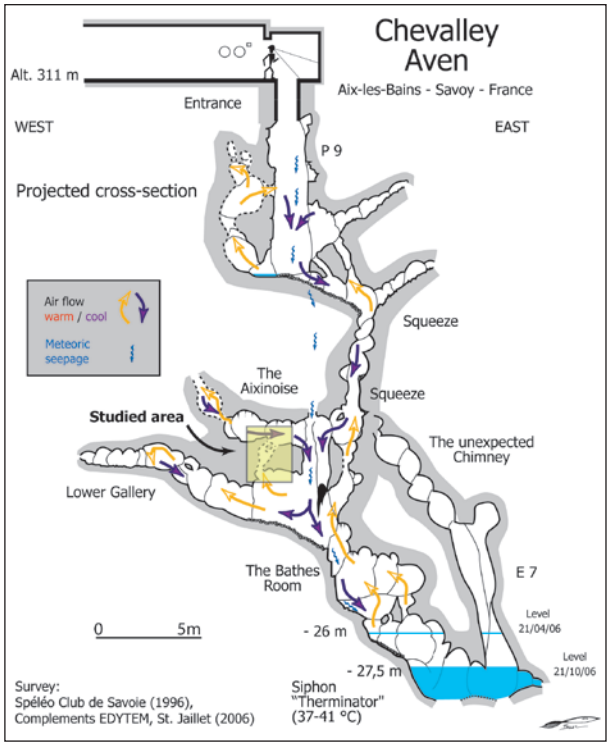


Fig. 7: Chevalley Aven cross-section. Air convection is shown, together with present water seepage originating from leakage of the thermal swimming pool located above. Before the building of the new thermal center in 1996, this water seepage was provided by natural rainwater infiltration through the soil.

the ceiling, and on the walls of the central sphere which is covered with condensation drips; conversely, cool air that sinks from an uppermost chimney warms up and produces evaporation at the upper mouth of the vent, which is dry. At the upper part of the lowermost neck evaporation also occurs from secondary convection cells in the central sphere.

The corrosion rate depends on condensation; thus corrosion occurs mainly on the ceiling and walls of the sphere that is gradually enlarged. The sphere ceiling and the upper part of the walls display a regular and smooth cupola shape made of a weathered limestone layer, 2-3 cm in thickness, where boxwork veins protrude. The condensation film dissolves the limestone micrite cement, dissociates the sparite grains, and progresses deepwards into the host rock as an incomplete weathering front (Zupan-Hajna, 2003). Along the walls of the sphere, the runoff from the accumulation of condensation dissolves the walls; consequently, no weathered material subsists over the lower rockwalls. At the base of the sphere, the condensation flow becomes saturated, and calcite deposits as small transparent crystals in a soft and wet paste.

Sulfate produced by replacement corrosion on the limestone wall is also washed down by condensation runoff. This process has also been noticed in Frasassi (Cigna & Forti, 1986). Runoff arriving at the base of the sphere becomes saturated with gypsum. Evaporation onto the "calcite grains wet paste" causes microcrystalline gypsum to deposit in a thin crust. Dripping from the top of the sphere may re-dissolve the gypsum that re-deposits downward into the narrow passage as gypsum flowstones, stalactites and columns made of massive gypsum crystals.

Biofilms coat most of walls, except: where intense condensation or runoff washes the walls; or where evaporation prevents the microbial development that needs permanent moisture.

Evaporation dries up the upper lip of the vent. Water is attracted by capillarity toward this dry zone that maintains a continuous recharge of dissolved species of carbonate. The evaporation allows calcite precipitation as a rim, similar to a small drapery, shaped by both airflow and evaporation (Fig. 9). Such cave features are characteristic of caves having a high thermal gradient and develop at the upper mouth of chimneys connecting cave levels where convection airflow cells occur. They may develop in the following situations:

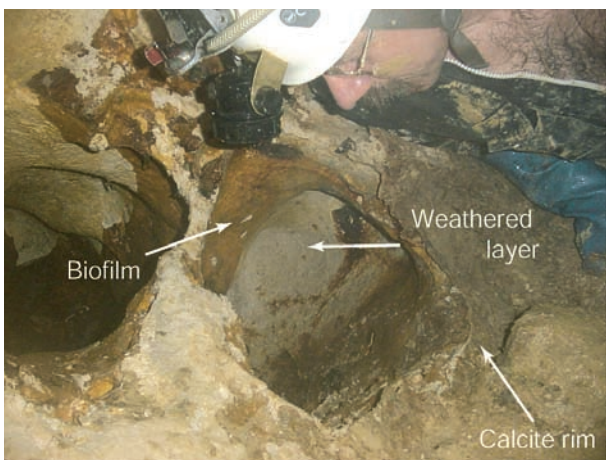


Fig. 9: Twin upper vents at the bottom of the Aixinoise gallery (photo. Ph. Audra).

1- in avens above a thermal water table located at depth, such as Józef-Hegy barlang, Budapest (auth. obs.);

2- where impervious layers covering karst prevent meteoric seepage that may homogenize temperatures throughout the cave profile (Wind Cave, Black Hills);

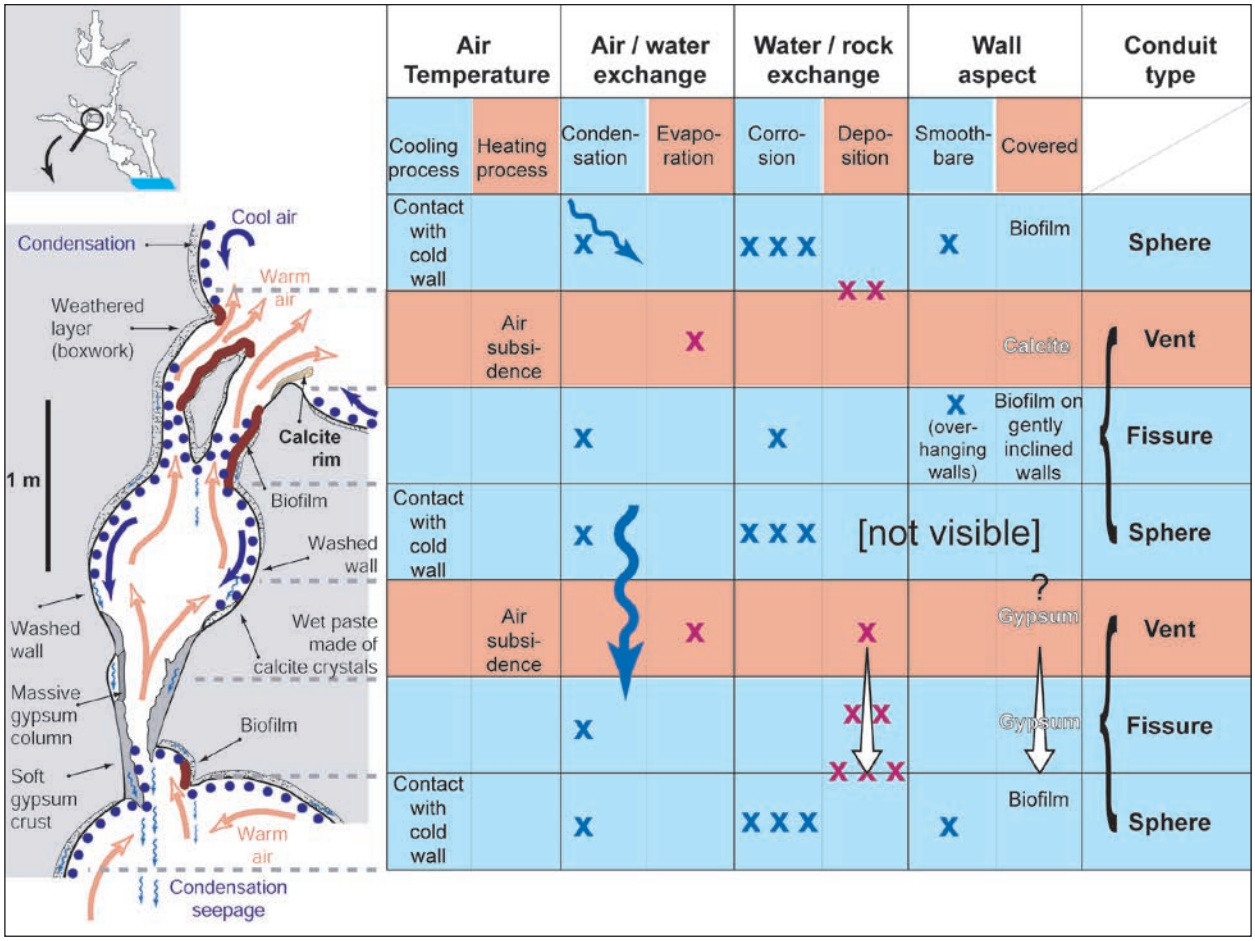


Fig. 8: Overview of the condensation-corrosion and evaporation-deposition processes. See text for details.

3- in arid areas for the same reason (Endless Cave, Guadalupe Mountains; see photography in Hill & Forti, 1997, p. 91);

4- in tropical caves where strong humidity and temperature gradients may exist between active galleries fed by surface seepage and galleries where strong airflow between entrances dries walls (NT2 Cave System, Kammouan, Laos; auth. obs.)

THE VENT, A CAVE FEATURE COMBINING CONDENSATION / EVAPORATION PLUS CORROSION / DEPOSITION PROCESSES

Figure 8 shows that the morphological setting strongly influences the distribution of processes.

- The upper mouth of the vent opens above the bottom of the uppermost sphere: the condensation water of the uppermost sphere flows away in another direction. Consequently, the vent collects its own condensation only that becomes visible in the lowest part of the narrow where clear surfaces covered with a weathered layer are visible.

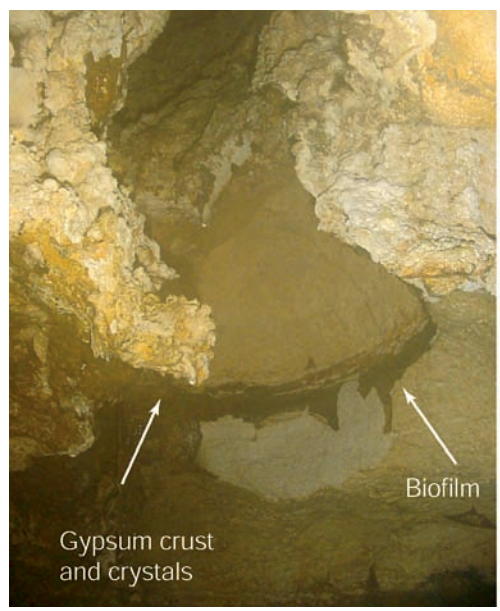


Fig. 10: The vent viewed from below, in the Lower Gallery; width of the vent is about 20 cm (photo. Ph. Audra).

- The lowermost vent located below the central sphere acts as a funnel that collects condensation from the upper narrow, from the central sphere that is the main runoff provider, and from its own condensation occurring in the lowermost part. Consequently, condensation runoff is important. Thus, by an overtopping effect, condensation runoff transfers the processes normally occurring at the base of the central sphere downwards. Instead of evaporating slowly, condensation water with high sulfate content flows downward into the narrow where it finally evaporates and where it deposits secondary gypsum as speleothems made of massive crystals. These gypsum deposits develop downward till they arrive at the ceiling of the lowermost sphere, where condensation and corrosion are predominant (Fig. 10).

Thus, a calcite rim may line the upper mouth of a vent if it is located above the drainage point of the upper sphere; on the contrary, condensation runoff washes and transports dissolved minerals downwards, to the lower narrow.

DISCUSSION

A POSITIVE FEEDBACK DEVELOPS SPHERES IN BUSH PATTERN

The distribution of corrosion and deposition processes produces a morphodynamic evolution according to the size of the conduits:

- spheres, where condensation-corrosion is high, evolve faster and tend to enlarge;
- narrow passages evolve slowly due to the small amount of condensed water collected, by neutralization of the condensation runoff after some distance, or evaporation.

Thus, a positive feedback tends to enlarge the wider places that evolve to form a spherical shape, whereas narrows remain small. Such a morphodynamic tends towards the development of stacked up spheres arranged in a bush-like pattern that are isolated by narrow necks.

THE ORIGIN OF SPHERES IN BUSH PATTERN REMAINS ENIGMATIC

The accurate observation of condensation-corrosion and evaporation-deposition processes clearly demonstrates that aerologic convections tend to exaggerate the difference in size of the voids located in the vadose zone just above thermal water table, and finally may develop as spheres in bush pattern and avens.

However, the origin of the Chevalley Aven is still obscure:

- did it develop exclusively from this aerologic convection process by hollowing into massive rock?
- did an older phreatic lift exist, that was drained by base level lowering and which evolved afterwards under aerologic conditions? And in this case, could a phreatic origin have initiated the development of the spheres? Flooding from meteoric invasions is also evoked as a contribution to the aven genesis, which would have enhanced mixing-corrosion processes typical of "transitional karst" (Hobléa, 1999; Dublyansky, 1997).

If the origin of the proto-cave is still under debate, we propose that a major part of the cave volume, if not the entire cave, could develop under aerologic conditions involving condensation-corrosion by a progressive upward propagation of voids into the rock mass which finally produces spheres in bush pattern. Similarly, in Movile Cave, condensation-corrosion is considered to be the main process of current wall retreat for air-filled passages above the water table (Sarbu & Lascu, 1997).

IMPLICATION FOR THE UNDERSTANDING OF HYPOGENIC WATER TABLE CAVES (VILLA LUZ, SERPENTS CAVE)

The Villa Luz Cave (Tabasco, Mexico) is similar to Serpents Cave, since it has an active water table cave with sulfidic springs upstream. Numerous avens are present, some being blind, some having broken through the surface as skylights. These avens are considered as phreatic lifts (due to their spectacular scallops showing rising flow) older than the drainage of the cave and the development of the main gallery (Hose & Pisarowicz, 1999). However, Villa Luz is a typical water table cave, clearly connected to the bottom of a small local valley and displaying a low gradient free surface flow. The avens starting from this water table gallery and developing upward cannot be older than the gallery itself. Consequently, they must have developed simultaneously to the main water table gallery (or later), thus not in phreatic conditions. The "phreatic scallops" that have been taken as indicators of upflowing, in fact would result from corrosive convection in the warm sulfidic atmosphere. Such airflow would produce features very similar to the scallops. Some of the avens still contain huge masses of replacement gypsum made of the accumulation of gypsum crust detached from walls. Other avens have breached through the surface, allowing the meteoric infiltration to wash away the gypsum deposits (Palmer, 2003).

In Serpents Cave, the Hell's Aven, which is the natural entrance, probably has a similar origin, that is to say a breakthrough surface of an aven made by corrosive "air" convections. However, and contrary to Villa Luz, the Hell's Aven is located just above the Alum spring (fig. 6); in this case, there remains the possibility that the aven could be an older phreatic lift drained after a base level lowering (Hobléa, 1999).

CONCLUSION

Observation of condensation and evaporation areas, corrosional morphologies, and of the distribution of the deposits have shown the strong relationship between condensation and corrosion, and conversely between evaporation and deposition. Moreover, the distribution of the condensation and evaporation processes strongly depends on the morphology of the cave. Condensation-corrosion tends to enlarge the largest voids, leading finally to a pattern of stacked spheres. These first conclusions, based on the study of cave features, indicate the possibility of speleogenesis mainly through condensation-corrosion. This hypothesis is currently under investigation. We are collecting data (temperature, airflow speed, pCO_2 and pH_2S, chemistry of condensate water), in order to calculate a budget of condensation rates and corrosion volumes which will be compared to the cave dimensions.

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THE ONE-EIGHTH RELATIONSHIP THAT CONSTRAINS DEGLACIAL SEISMICITY AND CAVE DEVELOPMENT IN CALEDONIDE MARBLES

DEGLACIALNA SEIZMIČNOST IN RAZVOJ JAM V KALEDONSKIH MARMORJIH: RAZMERJE ENA PROTI OSEM

Trevor FAULKNER[1]

Abstract UDC 550.34 :551.44(234.652)

Trevor Faulkner: The one-eighth relationship that constrains deglacial seismicity and cave development in Caledonide marbles

The formation of karst caves in Caledonide metamorphic limestones in a repeatedly-glaciated 40000km^2 region in central Scandinavia was initiated by *tectonic inception*, a process in which open fracture routes, primarily created by deglacial seismicity, provided the opportunity for subsequent dissolution and enlargement into cave passages in both deglacial and interglacial environments. The *tectonic inception model* built on reports of a 'partially detached' thin upper crustal layer in similar settings in Scotland and this paper shows that the present *maximum* subsurface cave distance (i.e. the distance of a passage to the nearest land surface) is commonly less than one-eighth of the depth of the local glaciated valley. This suggests that fracture generation was related to the scale of isostatic uplift and was partly determined by the magnitude of seismicity caused by the differential pressure change and differential uplift that occurred along valley walls as the ice margin of each of the major Pleistocene icesheets receded from west to east. The maximum one-eighth relationship is also commonly maintained in other Caledonide marble terranes in Scandinavia, Scotland and New England (USA), suggesting that many of the caves in these areas were formed by similar processes.

Key words: Caledonide, deglacial speleogenesis, epigean, ice margin, inception fracture, marble, neotectonics, one-eighth relationship, seismicity, stripe karst, subsurface cave distance, tectonic inception, Weichselian, Scandinavia.

Izvleček UDK 550.34 :551.44(234.652)

Trevor Faulkner: Deglacialna seizmičnost in razvoj jam v kaledonskih marmorjih: razmerje ena proti osem

Razvoj jam v kaledonskih marmorjih na periodično poledenelem 40000 km^2 velikem območju osrednje Skandinavije se je začel s tektonskim začetjem, procesom pri katerem so se prvotne prevodne razpoke ustvarile zaradi razbremenitev ob umikih ledenikov. Vzdolž teh prevodnih poti se v obdobju umikanja ledenikov in medledenih dobah razvijajo kraški kanali. Model tektonske incepcije, ki obravnava razvoj jam v "delno ločenem" vrhnjem delu skorje, temelji na opažanjih, da je največja globina jamskih rovov (pri tem je mišljena razdalja med površino in rovom) manjša od osmine globine lokalne ledeniške doline. To nakazuje, da je nastanek prevodnih razpok povezan z izostatičnim dvigom in delno pogojen z velikostjo seizmičnosti, ki so jo povzročili diferencialni pritiski in dvigi, ki so nastali ob ledeniških dolinah med umikanjem ledeniških pokrovov v smeri od zahoda proti vzhodu. Razmerje ena proti osem je značilno tudi v drugih območjih kaledonskih marmorjev v Skandinaviji, na Škotskem in v Novi Angliji (ZDA), kar kaže, da so podobni procesi botrovali nastanku številnih jam na teh območjih.

Ključne besede: Kaledonidi, deglacialna speleogeneza, podzemlje, rob ledu, incepcijske razpoke, marmor, neotektonika, razmerje ena proti osem, seizmičnost, kras v pasovih, razdalja površje-jama, tektonska incepcija, Weichselian, Skandinavija.

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INTRODUCTION

The repeatedly-glaciated 40000km^2 study area in central Scandinavia contains over 1000 individual metamorphic limestone (marble) outcrops and has nearly 1000 recorded karst caves with a total passage length >72 km (Faulkner, 2005 and 2006a, Fig. 1; Fig. 1). Fundamental differences between these caves and those formed in sedimentary limestones derive from the metamorphic grade of the host bedrock with its very low primary porosity and from the fine-scale foliations and the consequent lack of partings guided by the initial bedding. 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 in the marble that has been metamorphosed up to amphibolite grade. 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 the vertical dimension, whilst commonly remaining within 50 m of the overlying surface. Additionally, there are no regional-scale caves. This is despite some narrow marble outcrops being several tens of kilometres in length, forming *stripe karsts*. Commonly, just a single streamway underlies upper-level relict phreatic passages with few vadose elements, creating an *upside-down*, vadose-beneath-phreatic, morphology. Recharge to the karst is primarily allogenic and cave stream discharges commonly remain unsaturated with calcite (Lauritzen, 1981; Bakalowicz, 1984). 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. 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 (Lowe 1992; Lowe & Gunn 1997) is unlikely.

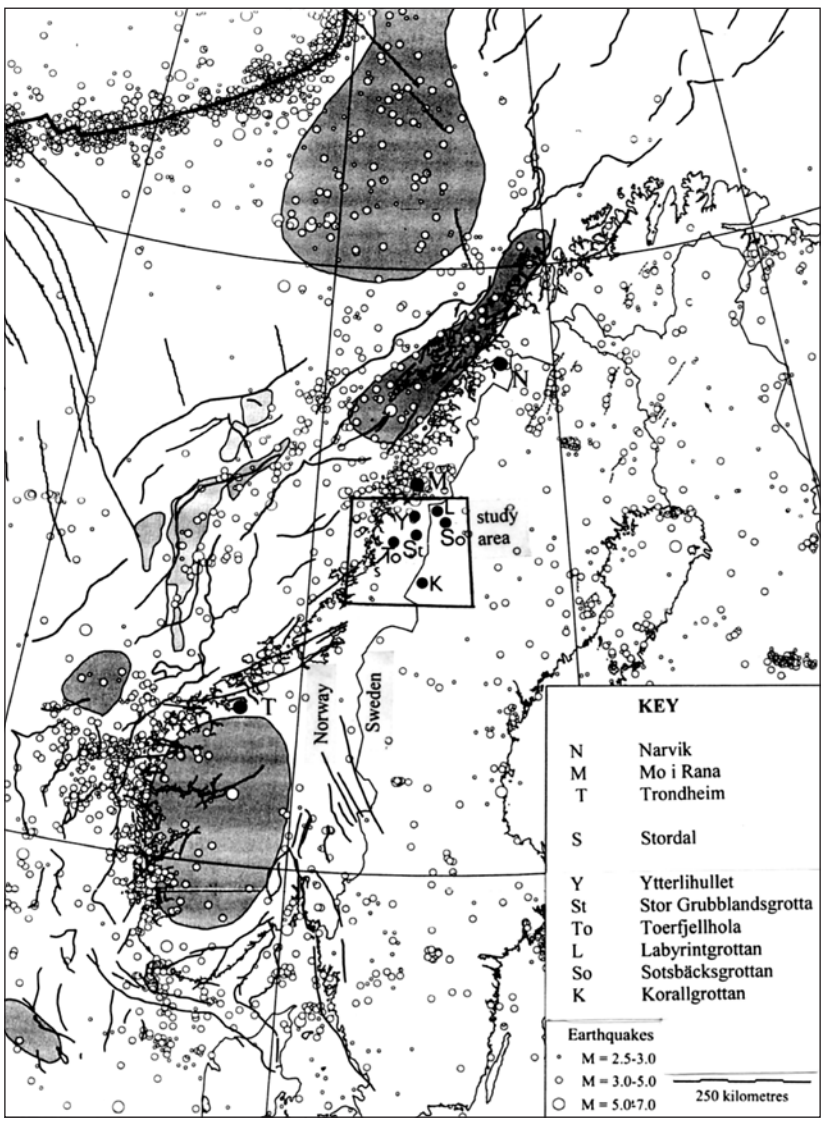

Fig. 1: Study area location, showing a) major caves and b) neotectonic earthquakes in Scandinavia from 1750–1999, from Dehls et al. (2000).

The *tectonic inception model* (Faulkner 2005; 2006a) proposed that it is only open fracture routes that could provide the opportunity for dissolution and enlargement into cave passages in the Caledonide marbles. It was 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 from the isostatic rebound that accompanied deglaciation at the end of each major Pleistocene glacial. Faulkner (2006a) described in detail the evidence for deglacially-induced earthquakes at the end of the Weichselian glaciation in Scandinavia. An additional mechanism for fracture generation may arise from earthquakes caused by the downhill sliding of a glacial ice mass (Ekström *et al.* 2003). The tectonic openings formed

along *inception surfaces* between the marble and adjacent aquicludes and at *inception fractures* that are entirely within the marble and are commonly (though not universally) parallel to, or orthogonal to, the foliation. The model built on reports of a '*partially detached*' thin upper crustal layer in similar settings in Scotland (Davenport *et al.* 1989). It is supported by observations of later neotectonic movements in most relict cave passages and sporadically on the surface from evidence such as fault gouges, slickensides and sharp edges that produce long narrow shadows. This paper explores relationships between cave dimensions and their local external geological and geomorphological attributes, providing more evidence in support of the model.

NEOTECTONICS AND CAVES

The areas of Scandinavia that are seismically the most active at present are the south Norway coast area, which has few carbonate outcrops, and that part of the county of Nordland in Norway that is north of the study area. That northern area, from Mo i Rana to Narvik, has caves up to 20 km in length and up to 580 m in vertical range (VR). In contrast, the study area *may* have a comparable density of karst caves, but with lengths and VRs only up to 5.6 km and 180 m (Faulkner 2005). The neotectonics map (Fig. 1) after Dehls *et al.* (2000) thus seems to suggest a rough relationship between the frequency and magnitude of earthquakes, and the dimensions of karst caves in a region. It is therefore hypothesised that the depths of inception fractures below the surface, and hence the total lengths of potential proto-conduits, are related to the magnitude, and perhaps to the frequency, of local deglacial earthquakes, assuming some correlation with the neotectonic pattern. Because that seismicity was related to the scale of isostatic uplift and to the differential pressure change that occurs along valley walls as a major icesheet recedes (Davenport *et al.* 1989; Ringrose *et al.* 1991), it follows that cave depth and length = function (fracture depth and extent) = function (strength of tectonic activity) = function (change of ice thickness during deglaciation).

From the above conclusion, the caves with the greatest dimensions should lie along the Swedish border area, because the icesheet was thickest there during each glaciation (probably ~2 km thick at the Last Glacial Maximum, covering all the local peaks) and because there are deep glacial valleys with extensive stripe karst outcrops. This setting should cause the largest earthquakes at the end of each Pleistocene deglaciation, and therefore the most extensive and deepest set of fractures. This may account, at least in part, for the presence near the border of four of the five longest caves of the study area: **Korallgrottan** (Sweden: 5.6 km), **Labyrintgrottan** (Sweden: 2.6 km), **Stor Grubblandsgrotta** (Norway: 1.9 km) and **Sotsbäcksgrottan** (Sweden: 1.9 km). The three deepest caves also lie in this region: **Ytterlihullet** (Norway: 180m), **Korallgrottan** (144 m) and **Sotsbäcksgrottan** (110 m). One other long and deep cave, **Toerfjellhola** (Norway: 1.9 km and 101 m), lies along the flank of a major mountain ridge that runs parallel to the coast.

SUBSURFACE CAVE DISTANCE

Faulkner (2006a) discussed the shallow nature of most cave systems in the study area, suggesting that caves in stripe karsts have formed entirely within an upper zone of fractured rock. It was hypothesised above that there is a relationship between cave VR (which is the vertical difference between the highest and lowest explored points of a cave) and the local change of ice thickness during deglaciation. A more direct relationship is likely to be with the maximum distance of cave passages from the overlying surface. This *subsurface cave distance* is taken to be the length along a line orthogonal to the surface and the centre of any intersected passage (Fig. 2), which, in the extreme case of a cave passage behind a vertical cliff, could be a horizontal distance.

In order to test the distance and relief relationship, the maximum subsurface cave distances of 39 of the deeper caves of the study area (obtained from cave survey sections) were plotted against the local relief differences (Fig. 3). The local relief differences were taken from 1:50000 topographical maps by measuring the height above the valley floor of the local ridge-shoulder, where a consistently steep slope profile becomes less steep. Caves can occur at any altitude along this profile, and the total lengths of the profiles were always less than a few kilome-

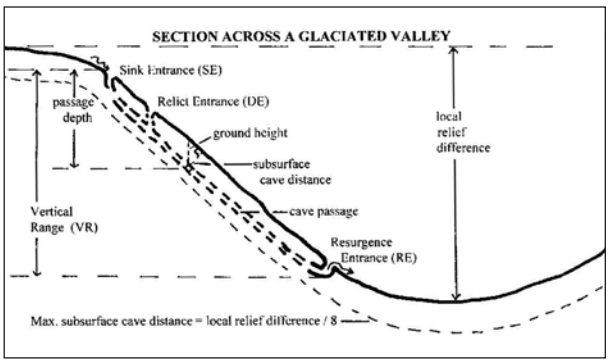

Fig. 2: Subsurface cave distance and other terms.

tres. There are few caves in areas of local relief difference of less than 100m, and none of these have VR>10 m.

The complete scatter diagram for all 884 recorded caves would show a poor correlation between subsurface cave distance and the local relief difference, because the mean VR of the caves is only 8.8 m and they occur in valleys of many different depths. However, Fig. 3 shows that the *maximum* distance of cave passages (and therefore of dissolutionally-enlarged inception fractures) from the surface is commonly one-eighth, or less, of the extent of the change of local relief. This maximum envelope for the relationship of subsurface cave distance to local relief difference appears to be approximately linear, at least for a local vertical relief of up to 400 m, and perhaps up to 800m. Most parts of the study area are represented by the caves shown in Fig. 3, showing that the one-eighth relationship probably applies across the whole area.

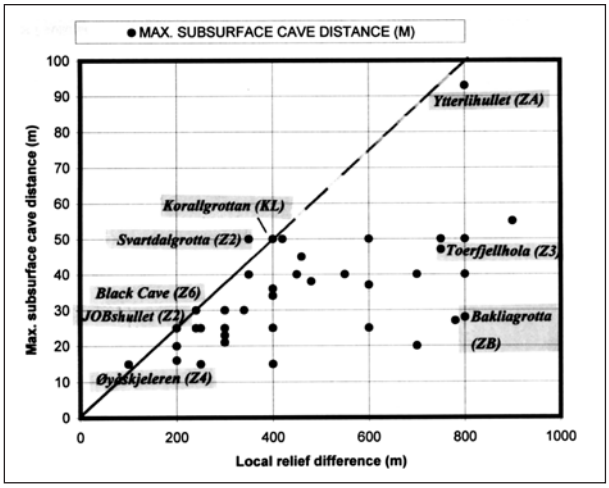

Fig. 3: Relationship between maximum subsurface cave distance and local relief difference. The straight line indicates the maximum one-eighth relationship that constrains nearly all the known caves in central Scandinavia, of which 39 of the deeper caves are indicated. The codes in parentheses give the geological zones used by Faulkner (2005). Z1–Z8, ZA–ZC and KL are located progressively eastward into Sweden. The wide geographical spread suggests that the maximum relationship applies throughout the study area.

THE INFLUENCE OF EXTERNAL ATTRIBUTES ON INCEPTION FRACTURES

The relationship between seismicity and cave development is supported by the evidence summarised by Faulkner (2005) and in Table 1. The karst type, for which three ranges of foliation dip were defined, influences the mean VR for the study area caves, but in a manner that is perhaps paradoxical. Thus, caves in Low Angle Karst (LAK, foliation dip 0–30°) tend to be deeper than average, caves in Angled Stripe Karst (ASK, 31–80°) have a similar mean VR to that of all 884 recorded karst caves, and caves in Vertical Stripe Karst (VSK, 81–90°) have a smaller mean VR. However, other cave dimensions vary less consistently with karst type.

Those caves in close proximity to a major thrust zone (designation T=1) have larger-than-average mean dimensions, whereas those in close proximity to a major igneous pluton, and therefore in marble 'remetamorphosed' by contact metamorphism (designation R=1) tend to be smaller. If the enhancing relationships are, in fact, directly controlled by the thrust attribute (rather than this just acting as a proxy for some other controlling variable), then this implies that the reactivation of old thrusts by deglacial seismic shocks promotes fracturing in any adjacent marble outcrops, creating longer and deeper voids for cave inception. Two mechanisms are possible to explain the restricting case. Firstly, the previous high-temperature contact metamorphism of metalimestone may reduce its fracturing ability, by making the rock more homogeneous. Secondly, the presence of a large igneous pluton (such as occur in the Helgeland Nappe Complex in the west: Faulkner, 2006a, Fig. 1) may, of itself, reduce the magnitude of local earthquakes, and, therefore, their ability to create long and deep fractures. Of the six caves discussed previously, three occur disproportionately near a major thrust zone, and none lie in an outcrop subjected to contact metamorphism (the main country rock being mica schist), again lending support to the earthquake relationship hypothesis.

The percentages of the 39 deep caves in Fig. 3 with external attributes R=1 or T=1 were compared with the same percentages in the total set of 884 recorded caves

External attribute	*Mean VR <8.8 m*	*Mean VR ~ c. 8.8 m*	*Mean VR >8.8 m*	*Notes*
Karst Type	VSK	ASK	LAK	Other cave dimensions (length, volume and cross-section) vary
Contact metamorphism (R)	R=1	R=0		Similar for all cave dimensions
Thrust proximity (T)		T=0	T=1	Similar for all cave dimensions
Cave Location (as defined by Faulkner, 2005)	Coastal, Valley Floor and **Paleic Surface**	**Gently Sloping** and Valley Wall	**Ridge** and **Valley Shoulder**	Locations in **bold** have similar influences for mean length and mean volume

Tab. 1: External attribute influences on mean cave vertical range. VSK: Vertical Stripe Karst, ASK: Angled Stripe Karst, LAK: Low Angle Karst.

in the study area. R=1 only occurs in 18% of the 39 caves compared with 23% overall and T=1 occurs rather more often (13%, compared with 11%). Although these percentages may be statistically similar, the differences at least suggest that the individual attributes that promote the deeper caves towards the one-eighth limit of the distance / relief relationship are the same as the attributes that influence vertical range, as shown in Table 1. Furthermore, caves lying below coastal, valley floor and paleic surface (i.e. one that has hardly been modified by glaciation) locations are under-represented by the 39 deep caves, caves beneath gently sloping and valley wall locations are similarly represented, and caves in ridge and valley shoulder locations have two to three times the representation. Thus, the steeper is the local topography at the cave location (as defined by Faulkner 2005), then the more likely a deeper cave will be formed.

The proximity of the caves in Fig. 3 to the one-eighth 'limit' can be considered in terms of the competition between their various external attributes. Only **Øyåskjeleren** and **Svartdalgrotta** exceed the normal maximum relationship, with subsurface cave distances that reach about one-seventh the local relief difference. Not only are these two caves situated in the valley shoulder cave location, they also both lie behind large vertical cliffs, suggesting that the effect of seismic shock is magnified even more by very steep topography. In the case of **Svartdalgrotta**, this overcomes the restrictive effect of an adjacent, but small, intrusive outcrop. **Korallgrottan** is shown at the one-eighth limit, probably because of its proximity to a thrust, despite lying essentially in a valley floor location. (However, its maximum distance from the surface is only estimated approximately). **JOBshullet** also lies on the one-eighth line, despite being surrounded by an enormous granite outcrop, probably because it has its cave location in a narrow ridge of marble, which is seismically very favourable. Fractures in ridge and shoulder locations are also more likely to open farther by ice wedging and by gravitational mass movement, explaining why caves in these locations have the largest numbers of entrances per cave, creating many *through caves* (Faulkner 2005).

It was suggested by Faulkner (2006a) that part of **Ytterlihullet** achieves its exceptional (for this study area) 93m subsurface cave distance because it occurs in LAK with interlayered amphibolites that acted as inception horizons. This remains a valid factor, but the cave is also situated at the eastern shoulder of Bryggfjelldal, one of the largest and deepest glaciated valleys in central Scandinavia (Fig. 4). This is 5000m wide and 800m deep and lies below the Okstind mountain range that has the area's largest remnant glacier. The cave is thus ideally situated to take advantage of deep fractures produced by high-magnitude seismic events that shook the area after each of its deglaciations. From Fig. 3, inception fractures formed along the observed amphibolite layers still lie within the limits of the one-eighth relationship.

From the evidence in Fig. 3, fractures are created only rarely up to the one-eighth 'limit'. Additionally, their enlargement into cave passages at the depths reached must be constrained by the extent of the marble outcrop in that area, and by the geological and topographical inheritance: passages can only develop in size (even under deglacial conditions) if there is a suitable hydraulic pathway. Deep fractures that have no route back to the surface can only fill with static water, and not enlarge. Thus, some caves with subsurface distances that are well inside the one-eighth line can be explained by a lack of suitable marble outcrop. At the extreme, areas that do *not* exhibit cave systems, or that contain unexpectedly shallow systems, despite containing extensive striped marble outcrops, such as Stordal near the coast (Fig. 1), may be areas of anomalously low seismicity. Indeed, the Stordal marble lies along the floor of a glacially-rounded valley

Fig. 4: Bryggfjelldal from the entrance to Naeverskardhullet. The cave system has formed at the valley shoulder location, which is favourable for the seismic creation of fractures during deglaciation.

that is surrounded by large plutons of quartz diorite and trondheimite, so that its lack of karstification can be ascribed to the contact metamorphism restriction and to its location. The many short and shallow caves at Övre Ältsvatn in Sweden commonly lie in LAK, 'remetamorphosed' in places by granitic intrusions, on a paleic surface plateau. Thus, their small dimensions probably derive from both contact metamorphism and their rather flat cave location. These reduce local seismic activity and, additionally, the paleic surface location restricts the opportunities for deep hydrogeological drainage.

The conclusion from the above commentary is that the largest positive influence on the production of long and deep inception fractures and therefore on cave dimensions is the seismic magnification that can occur at ridge and shoulder cave locations, especially if near a reactivated fault or thrust. Inception fracture depths are restricted near igneous intrusions and at coastal, valley floor and paleic surface cave locations; foliation dip has a less consistent influence.

Cave	*Karst Type*	*Mean tier spacing (m)*	*Mean shaft spacing (m)*	*Spacing ratio shaft/ tier*
Klausmark System	ASK	3	3–30	1–10
Two Bridges Cave	ASK	4	20	5
Hornet Pot	ASK	6	30	5
Lislvatngrotta	ASK	3	25	8
Tourist Cave	ASK	4 - 8	22	3–5
Svartdalgrotta	LAK	10	10–20	1–2
Neptune's Cave	ASK	5 - 10	10–15	1–3
Balcony Cave	ASK	2	4	2
Toerfjellhola	VSK	5	12–22	2–4
Øyåskjeleren	VSK	5	8	2
Eiterådalgrotta	ASK	5	50	10
Sirijordgrotta	VSK	8	16	2
Håpgrotta	ASK	3	10	3
Green Valley Cave	VSK	2	5	2.5
Jordhulefjellhullet	VSK	4	20	5
Pustehola	ASK	6	12	2
Brown Stains Cave	ASK	4	10	2.5
Sarvenvårtoehullet	ASK	5	20	4
Gevirgrotta	ASK	5	15	3
Sarvejaellagrottene	ASK	8	12	1.5
Jegerhullet	ASK	3	10	3
Etasjegrotta	VSK	2	7	3.5
Invasjonsgrotta	VSK	13	40	3
Anastomosegrotta	VSK	3	8	3
Møllebekkgrottene	VSK	2	8	4
Geitklauvgrotta	VSK	3	6	2
Kompassgrotta	VSK	5	10	2
Blåfjellgrotta	VSK	4	10	2.5
Høgligrotta	ASK	4	10	2.5
Kvannlihola	VSK	5	50?	10
Grønndalsgrotta	LAK	8	16	2
Gielasvaratjgrottan	LAK	2	3	1.5
Sotsbäcksgrottan	LAK	10	20	2
Korallgrottan	ASK	4	18	4
SUMMARY	All	2–13	3–50	1–10
MEANS		5	16	4.6

Tab. 2: Spacing between passage tiers and between shafts. For karst types, see Table 1. Caves are Listed W-E.

FRACTURE SPACING

The surveys of 34 of the more complex caves in the author's cave databases reveal (Table 2) that the mean vertical spacing between sub-horizontal phreatic passage tiers varies from 2–13 m (overall mean c. 5 m) and the mean horizontal spacing between near-vertical shafts and joints varies from 3–50 m (overall mean c. 16 m). The ratio of mean shaft spacing to mean tier spacing for each cave varies from 1–10 (overall mean c. 4.6). All these ranges appear to be independent of karst type, as previously defined. Because Marrett *et al.* (1999) provided evidence that fracture apertures in limestone follow a power-law scaling, it might be assumed that, at any one time and place, fracture apertures commonly decrease with depth, so that the horizontal and vertical separations between

tectonic fractures of a particular aperture size increase with depth, i.e. they become less frequent. However, from the survey sections of the two caves with the most passage tiers in the study area (8 in **Toerfjellhola** and c. 20 in **Etasjegrotta**), there is little evidence of an increase in fracture spacing with subsurface cave distance, which in these cases approaches 50 m. It is assumed therefore that within the "*partially detached thin upper crustal layer*" of Davenport *et al.* (1989), fractures occur at essentially random intervals, but that the distance of this detachment from the contemporary surface equals the maximum subsurface cave distance. This random arrangement within an upper crustal layer contrasts with the finding of Milanović (1981, p48) that the *"depth of karstification*" found in boreholes in sedimentary limestone obeys an exponential law.

CONCLUSIONS

This paper has shown that the present *maximum* "subsurface cave distance" is commonly less than one-eighth of the depth of the local glaciated valley, suggesting that fracture generation was related to the scale of isostatic uplift and was partly determined by the magnitude of seismicity caused by the differential pressure change and differential uplift that occurred along valley walls (which are typically aligned N-S) as the Weichselian and earlier icesheets receded from W-E.

Some stripe karst outcrops in central Scandinavia also support permanent bodies or flows of water (lakes, tarns and streams: Faulkner 2005), which suggests a sporadic *lack* of speleogenesis. Thus, it is concluded that tectonic activities and fractures occur in *clusters* along the various outcrops. As each successive glaciation deepened glacial valleys and fjords further, the ice thickness variation, and therefore the intensity of seismic shocks in some earthquake zones, must have increased during the time of the Mio–Plio–Pleistocene glaciations. However, because the valley geography remained roughly constant, each cluster of large seismic shocks remained approximately concentrated on the same position. Hence, each successive deglaciation commonly re-activated previous fracture sets, and extended them farther along, and farther below, the contemporary surface than the previous one. Because the present maximum subsurface cave distance is almost universally one-eighth the range of local relief, it seems likely that both the depth of the partially detached crustal layer and the maximum subsurface distance of cave passages also increased at one-eighth the rate of glacial valley deepening. However, acting synchronously with this deepening, there is also the probability that previous palaeo passages were removed by the erosional lowering of the surface by glacial stripping. The competition between these two processes was explored further by Faulkner (2005), to create a general Caledonide model of cave development. In this model, fractures were created by a pulse of deglacial seismicity that accompanied the recession of each ice margin, after which the presently relict phreatic passages enlarged by deglacial speleogenesis in cold water with little CO_2 (Faulkner 2006b) and the mainly vadose passages enlarged during interglacial speleogenesis.

The general model was also found to be valid for karst caves in the other non-Arctic metamorphic Caledonide terranes of northern Scandinavia, southern Scandinavia, New England (USA) and in the Dalradian Supergroup outcrops in Scotland and Ireland (Faulkner 2005), where the maximum one-eighth relationship is also commonly maintained. Only in some deep caves in northern Norway (e.g. **Tjoarvekrajgge**, the **Okshola / Kristihola** system and the **Greftkjelen / Greftsprekka** system) is the one-eighth relationship (dramatically) exceeded. The likely explanation is that tectonic inception at such caves was promoted by longer-timescale, possibly aseismic, processes such as the long-term uplift of the Scandinavian landmass or the spreading of the Atlantic Ocean, rather than mainly by deglacial seismicity caused by rapid uplift. In at least the first two of the given examples, their relatively large subsurface cave distances may also be facilitated by the LAK nature of their (medium grade) marble outcrops, providing more opportunities for 'conventional' inception horizons to operate (c.f. **Ytterlihullet**, as discussed above). The island of Shetland, also within the Dalradian Supergroup, was found to have no caves within its long marble stripe karst outcrops and only small exokarst features. Hence, Shetland provides the (null) end member of a Caledonide tectonic inception series, because the Weichselian ice sheet was much thinner there, the relief is modest, and there was little deglacial seismicity. Indeed, the island was *uplifted* during glaciation and the present land surface is actually *falling* during the Holocene, so that some valley floors are now drowned by the sea to create inland waterways that are locally called voes.

If the conclusions in this paper are correct, the existence of cave passages in Caledonide marbles can be used as a proxy for the formation of tectonic fractures, and the evidence provided should be important in the field of seismology: it implies that most fracture creation arises

from local earthquakes caused by adjustment to local-scale differential ice load, and arises only exceptionally from earthquakes or slow tectonic movements caused by Scandinavian-scale isostatic uplift or by the present mid-Atlantic ridge-push that is widening the ocean. Additionally, the presence and structure of the cave passages themselves and any internal neotectonic displacements may provide a method to deduce the strength and nature of the deglacial earthquakes.

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COBISS: 1.01

FAULT DETERMINATION DUE TO SINKHOLE ARRAY ON LAR VALLEY, NORTHEAST OF TEHRAN (IRAN)

DOLOČANJE PRELOMOV NA PODLAGI RAZPOREDITVE POŽIRALNIKOV V DOLINI LAR, SEVEROVZHODNO OD TEHERANA (IRAN)

Ahmad KHORSANDI[1], Takao MIYATA[2]

Abstract UDC 551.243.1(551)

Ahmad Khorsandi & Takao Miyata: Fault determination due to sinkhole array on Lar valley, northeast of Tehran (Iran)

The main objective of this paper is to present an approach to identify active faults in karstic enviroments. This is achieved by a releasing relationship between sinkholes or dolines formation, array and active faults mechanism. In this research , Lar valley on the Northeast of Tehran, Capital of Iran was selected as a case study. The sinkholes array in the valley shows that their formation and location is influenced by active faults. As a result of active faults mechanism, a number of young and old dolines have been formed on north and south of the study area. According to Aerial Photographs, Satellite images and geological logs corelation three major active faults were distingushed in the study area specially under Lar dam structure. Two of the faults are elongated to the north and the one extends to the south, seven sinkholes were formed on faults. Based on the available evidences, it is assumed that the formation and array of dolines in the study area has been formed and controlled by active faults. Conversely , it is deduced that faults activity may be determinated by sinkholes formation and array. This results may be applied for the similar cases of world,s karstic belt.

Key words: sinkhole array and formation, active fault determination, Lar valley, Iran.

Izvleček UDK 551.243.1(551)

Ahmad Khorsandi & Takao Miyata: Določanje prelomov na podlagi razporeditve požiralnikov v dolini Lar, severovzhodno od Teherana (Iran)

Članek poskuša predstaviti pristope k ugotavljanju aktivnih prelomov na krasu. Metoda temelji na ugotavljanju razmerij med nastajanjem in porazdelitvijo požiralnikov (oziroma vrtač), ter na aktivnem tektonskem mehanizmu. Obravnavano je območje doline Lar, severovzhodno od Teherana. Razporeditev požiralnikov vzdolž doline nakazuje, da je nastanek oziroma lokacija požiralnikov povezana z aktivnimi tektonskimi premiki ob prelomih. Na severni in južni strani doline je nastalo večje število relativno mlajših oziroma starejših vrtač. S pomočjo satelitskih posnetkov in korelacij so določili tri večje aktivne prelome na obravnavanem območju, posebej blizu jezu Lar. Ob prelomih, od katerih dva vpadata proti severu in eden proti jugu, je nastalo sedem požiralnikov. V skladu z razpoložljivimi podatki sklepajo, da je nastanek in razporeditev požiralnikov posledica aktivnih tektonskih premikov ob prelomih. Sklepamo lahko tudi obratno, torej da so aktivni premiki ob prelomih povezani z nastankom in razporeditvijo požiralnikov. Rezultati raziskave bi bili lahko uporabni v številnih podobnih primerih, ki se pojavljajo na kraškem terenu širom po svetu.

Ključne besede: nastanek in razporeditev požiralnikov, aktivna seizmika ob prelomih, dolina Lar, Iran.

INTRODUCTION

To understand the dolines formatin which is affected by active faults mechanism, it is neccessary to identify active faults on the basis of array formation of the Sinkholes. In order to protect the areas with sinkhole formation we need to consider following cases:

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1-Urban area
2-Farmland
3-Irrigation systems
4-Pump station
5- Electrical power generation
6-Water well muding
7-Collaps of different structure and buildings
8- Induced earthquakes
9- Unstable earth around sinkholes

There are a number of case studies that present strong evidences of the above mentioned list.. Milanovic(1981) discussed of tectonic influence on dolines formation proccess, Rezai and Zamanian in 1988 demonstrated sinkholes array (260 sinkholes) that is formed by thrust fault. However ,the influence of active faults is observed on karstification and hydrogeology regime in west of sweden (Herold et al.,1988). Sustersic (2003) states which water collector of Dollines is controled by active faults crushed zone. A number of researches have stated active faults and tectonic affects on karstification and groundwater (Fazeli, 1988; Kenz, 1988; Edgell, 1993; Celik and Onsal, 1999; Maloszweki et al., 1999; Kusamayudha et al., 2000; Taylor and Howard, 2000; Fernandes and Rudolph, 2001; Clarke, 2003). Haydari et al 2003, Amiri 2003 , Sadati and Mohamadi 2003, observed formation of many sinkholes (39) with different sizes on faults direction , in Hamadan plain, in northwest of Iran. The formation of sinkholes has led to many problems for farmland, irrigation systems, water wells and power electric generation. dolines formation may also occure gradualley or suddenly in urban area, this was observed in 1981 winter park sinkhole in Florida, which destroyed a large part of a city block, sent shock waves throughout the popular media (Edlane 1993). The objective of this paper is to demonstrate relationship between Lar valley sinkholes array and active faults .since occurrence of sinkholes affected by active faults mechanism in urban area and plains causes a great deal of problems, it is important to study dolines in order to protect urban area and plain so that reduce cost of damages. In other hand ,on basis of above experiences ,determination of active faults and their locations is possible ,that is important in seismology so that the information apply for buildings ,urban area and other structures damage protection.

The case study of Lar valley sinkholes resulted in identification of active faults and their effect on formation of dolines.The results of this survey shows that ,it is possible to estimate active faults and their location on basis of sinkholes situation along faults direction in world which their condition are similar

LAR VALLEY SINKHOLES AND ACTIVE FAULTS CHARACTERESTIC

Lar region is located at northeast of Tehran city, Iran with E51°,35' to E52°,00', longitude and ; N35°,51' to N36°,5' latitude(Fig 1a). It is a large valley with an area of 724 km2,which is in Alborz mountains,part of Alp- Himalyaan orogenic belt, that is located on world karstic belt. Mount Damavand with elevation of 5670 m and Lar river in the east part with elevation of 2460 m are respectively highest and lowest points of Lar valley.

Lar reservior dam which has been constructed in the east of study area has leakage since refilling the reservior and few young dolines have been formed in lake deposites behind the dam (Asadi 1995).

Stratigraphic sequence of the study area is as follows:

Mezozoic: The Mezozoic in the study area is contained of Jurassic system which is the limestone (Lar limestone). It is a thin-bedded to massive which contains many karstic phenomena and is fractured by tectonic. The Lar formation is located in right and left bank of the Lar dam. (Figs 4 and 6).

Cenozoic: The Cenozoic includs Quaternary lava and alluvium. The lava is outcroped in the middel and left banks of the Lar dam (Figs 4,6). It is contained Trachy andesite and Trachyte. The Alluvium is young,old and lake deposit (Figs 2,4 ,6) (Shahrabi and Sidi, 1984; Giahi, 1989). The age of alluviall is Holocene that deposited about 38500 years ago (late Plestocene) (Allenbach, 1966).

SINKHOLES OF THE LAR VALLEY

Nine sinkholes are developed in the sediments, which filled the Lar dam Lake banks (Figs 1b, 2,4,5,6). The array of the sinkholes is in the direction of E-W. Four of them are young, with a sharp outline (Figs 2,4,5), appeared during 1980-1989. Their diameters vary between 5-40 m and depths of 5-22 m. The ratio of diameter to depth was computed in the rang of 0.6 to 4 (Table 1).

The ancient sinkholes are Five having collapsed walls, which can be found on course-grain alluvial (Figs 2, 4 ,5). It is noted that the depth is considered by low, thus is due to the fact that collapsed wall sedimentation is deposited into hole (Table 1). The ancient sinkholes diameter is 5 to 80 m and their depth vary between 4 to 5 m, except S8 and S9 in Table 1.

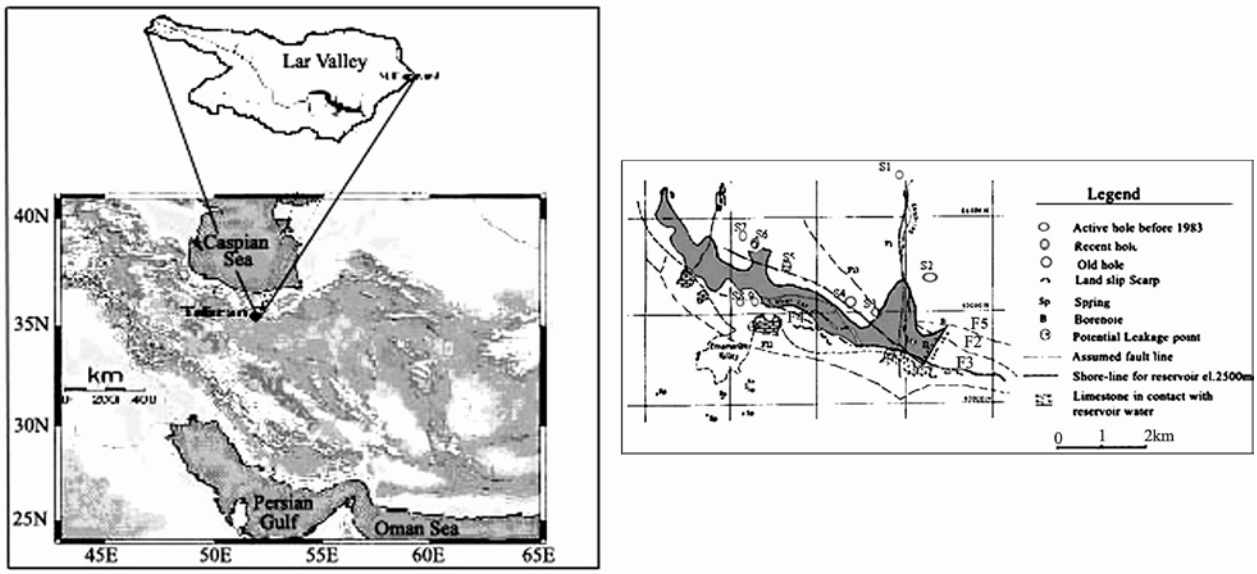

Fig.1: a) Location of the Lar dam region, northeast of Tehran. b) Location of the Lar dam and distribution of sinkholes and active faults.

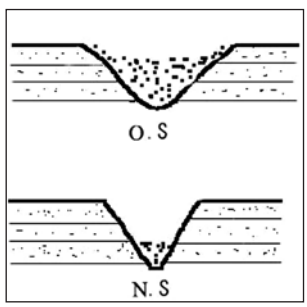

Fig. 2: Cross section of young (N.S) and ancient sinkholes (O.S) that shows erossion filling and collapse.

LAR VALLEY FAULTS

The Lar Valley fault elongated from the Lar dam in east to the west of valley (Fig 1b). Its dimensions extend, about 27 km long and 15 km wide. However the study area was selected 5 km long and 3 km wide due to the existance of the faults and sinkholes. Many information of the faults extent observed on base of airphotograph, satellite images, excavation data and boreholes geological logs corelations.

Lar valley airphotograph and Satellite images study delineate F1 and F2 faults (Fig 1b).

Geotechnical and Engineering Geology surveys of gallery and boreholes in the Lar limestone distingushed many faults and karst phenomena (i.e cave, gallery,….) (Tehran Water Org., 1976; Giahi, 1989). The study of Lar formation (Jurassic) excavations shows that it has a thickness from the surface to 140 m below, and there after karaj formation (Eocene) is observed, which are good evidences to prove the existance of F4 thrust fault in lar valley (Fig 1b and 6). A big cave was also observed in 105-106 m deep. In borehole from one of the galleries,13 caves were observed in 240 m depth,which is a good evidence on the existance of the fault and its influence on karstification. In boreholes from two galleries, erosion and crushing are evident which prove existance of fault.

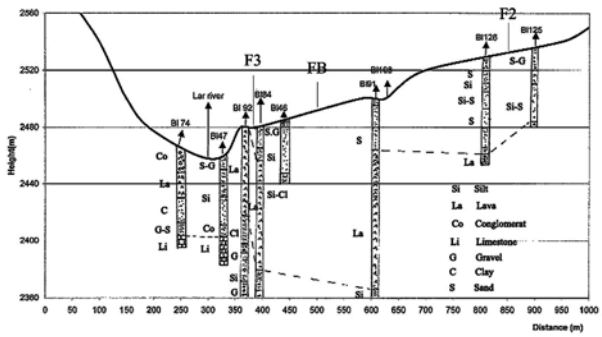

Fig. 3: Geological log of boreholes in direct to dam axis in Fig.1b, With the important F3, FB faults and F2 fault that distingushed by displacement Formatio in boreholes.

In this research many boreholes were selected along the Lar dam axis. (Fig 3) Correlation of boreholes geological log has distingushed three active faults and their mechanism (F2, F3 and FB in Fig 3).

Three types of faults are mainly determined in the study area and their around , normal, reverse and thrust faults.

Normal faults are principally elongated in three directions namely NW-SE, NE-SW and N-S, they are located in the south and northeast of the valley. Reverse faults have NW-SE direction and dip strike toward NE. These are located at southwest of the Lar valley. Thrust faults are directed NW-SE with dip strike toward NE which are located in the south of valley. Further information about faults were also obtained from the study area that are discussed here.

No	*Symbol*	*Geographical Cox*	*Geological Formation*	*Location*	*Diameter-Depth*	*Date of formation*	*Fault*
1	S1	51, 59.5-35, 55.5	Lake Deosit	Lar, Dalichai across	---------	Ancient	Dalichai fault
2	S2	51, 59.5-35, 54.7	Lake Deosit	// //	Dia.=10 m Depth=5 m	1980	Dalichai, F3 fault
3	S3	52, 58.7-35, 54	Alluvial, lake Deposit	Nw of Dam	Dia.=5 m Depth=22 m	Ancient	F3 fault
4	S4	51, 58.7-35, 54	Alluvial, lake Deposit	Nw of Dam	Dia.=13 m Depth=23 m	1988	F3 fault
5	S5	51, 57.7-35, 54.5	Alluvial, lake Deposit	Nw of Dam	Dia=5 m Depth=18 m	1988	F3 fault
6	S6	51, 57-35, 54.9	Alluvial, lake Deposit	Nw of Dam	Dia.=80 m Depth=4 m	Ancient	F3 fault
7	S7	51, 57.1-35, 54.8	Alluvial, lake Deposit	Nw of Dam	Dia.=40 m Depth=10 m	1989	F3 fault
8,9	S8, S9	51, 57-35, 53.5	Alluvial	Sw of Dam	----------	Ancient	F4 fault

Tab.1: Characters of existing sinkholes of Lra valley.

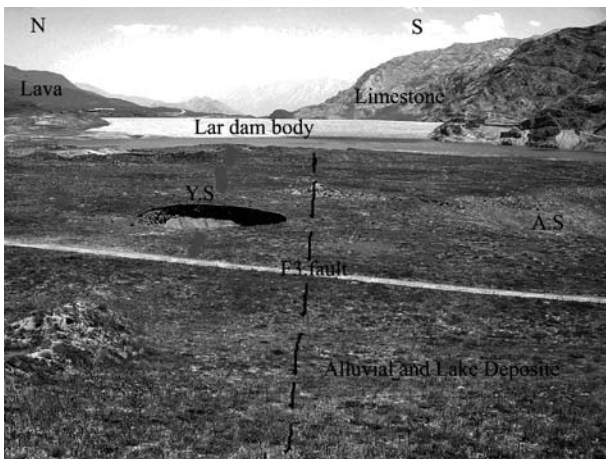

Fig. 4: Photo of sinkholes around Lar dam. AS is ancient sinkhole and YS is young sinkhole that assumed, their array influenced by the F3 fault.

FB fault is located between the B1 84 and B1 91 boreholes (Fig. 3) which displaced the lava about 40 m high. It is normal and active fault. F1 fault is located between B1 125 and B1 126 borehole (Fig. 3), it displaces natural drainage system and changes the geologic features of lava (i.e. color, composition and thickness of the lava). It is strike-slip and active fault which has 11 km long. The width of crushed zone is 50-10 cm and two ancient sinkholes were formed along that F3 fault is normal with 8 km long, which passes under Lar dam foundation, it displaces Lava 20 m high (Fig. 3). This is active and three young sinkholes were formed along that (Figs. 1b, 4 and 6).

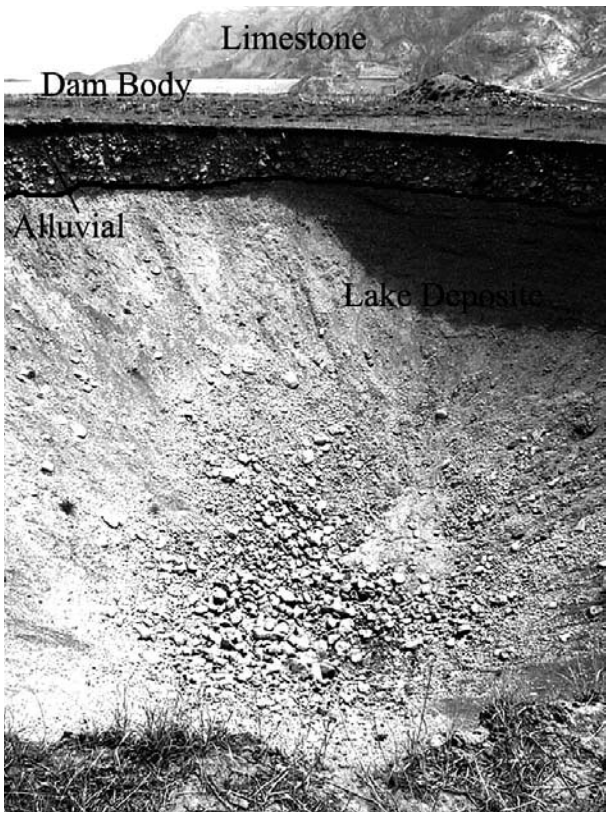

Fig. 5: Photo of young sinkhole containing lake deposit and alluvial.

The F4 fault is located in south of Lar valley, two old sinkholes are located along that (Figs. 1b and 6). It is

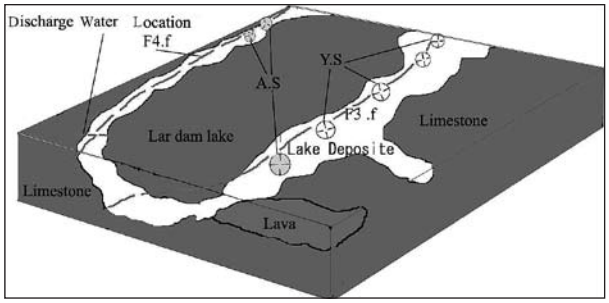

Fig. 6: Schematic diagrams illustrating the relationship between sinkholes and the F3 fault. Jurassic limestone; Lava is the Andesite and Trachyandesite.

a thrust fault sloping towards south with crushed zone width approximatly 30 cm.The crushed zone may be suggested to operate as an unerground channel to carry uncontrolled water discharge (Giahi 1989) of Lar Dam reservior further downstream (Fig 6).

Many evidences of structural geology imply that the mechanisms of F3 and F4 fault in the southern and F1 fault in the northern sides of the valley are responsible for new graben formation.

DISCUSSION

Finding and determining the active faults is an important topic in earth sciences. It is possible to determin them in karstic environment due to dolines array along faults in recent alluvial,where the fault is covered by alluvial.

The conclusion of research in Lar valley, distinguished that some old and young Sinkholes are formed by faults mechanisms in recent alluvial and lakes sediments. Since dolines are formed in the direction of faults, this, in turns may be strong evidence of faults Activity (USBR 1978). Active and capable faults of the study area are F1, F2, F3, F4 and FB. These faults were characterized by study of aerial phothographs, satellite images, and excavation data and geological log correlation.Fourthermore, several karstic phenomenas i.e caves, cavities and galleries have been formed in Lar limestone depths where they are superimposed on crushed zone and faults direction. Thus, the most appropriate guideline for primary identification of active faults in karstic enviroments is the presence of sinkholes array there are other methods to indentify active faults underground.These methodes are geoelectric, geoseismic, GPR, trench, borehole excavation, well logging and groundwater surface anomally study. However here are some problems with applying these methods for active faults finding.Griffiths(1986) stated that geoelectric method requires high anomaly around faults. Geoseismic method makes interpretation of fault identification very hard and may not be quite right. In GPR method, the depth of the fault should not exceed 50 m (Miyata 1999),while trench and borehole excavation as well as logging methods require a fair knowledge of location and depth of fault. In fact, these methods are complementary for faults identification which may be costly and more often are not able to determinne active faults. Groundwaters level anomaly needs countinuous monitoring of groundwater level variation which may be applied in alluvial plains (Sarvar 2005).

CONCLUSSIONS

Sinkholes array and their relationship with Lar valley fault implies that fault activities depend upon spatial distribution of sinkholes array, on faults direction.

Four young and five old dolines exist in the study area of Lar valley,they are elongated NW-SE which are superimposed on Lar valley faults direction. Lar valley faults are identificated as F1, F3, FB and F4, F1 is 11 km long with vertical diplacement about 20 m with two young sinkholes that formed on its direction that is a good evidence of fault activity, F3 was identificated with 8 km long and 40 m vertical displacement. Two young dolines along fault direction were formed after Lar dam refilling which can justify the active fault. FB has 5 km long with 40 m vertical displacement. Its mechanism,which is resulted from geological logs corelation implises fault activity. F4 was characterised with 12 km long and two old sinkholes were formed on its direction.This fault on basis of available data is not active.

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ALLUVIAL FANS ON CONTACT KARST: AN EXAMPLE FROM MATARSKO PODOLJE, SLOVENIA

VRŠAJI NA KONTAKTNEM KRASU: PRIMER IZ MATARSKEGA PODOLJA, SLOVENIJA

Uroš STEPIŠNIK[1], Mateja FERK, Petra GOSTINČAR, Luka ČERNUTA, Karmen PETERNELJ, Tomaž ŠTEMBERGAR & Urša ILIČ

Abstract UDC 551.448 (497.4)

Uroš Stepišnik, Mateja Ferk, Petra Gostinčar, Luka Černuta, Karmen Peternelj, Tomaž Štembergar & Urša Ilič: Alluvial fans on contact karst: an example from Matarsko podolje, Slovenia.

Several types of contact karst are found within the Slovenian karst, but the most common is the ponor type, which usually appears between flysch and limestone. The most extensive contact of this type is in western Slovenia, in the area of Matarsko podolje, where a variety of typical contact karst depression features can be found. In the northwestern part of Matarsko podolje two types of alluvial fans occur. One alluvial fan has an active process of alluvial sedimentation on its surface and is distinct in shape, just like alluvial fans in fluvial geomorphic systems. The other type represents relict alluvial fans on contact karst. They are fan-shaped surface features in carbonate bedrock. Their formation is a result of the gradual removal of alluvial cover and the chemical denudation of carbonate bedrock on areas that were covered by alluvial fans. Geomorphological features and processes on alluvial fans, and the influences of alluvial fans on the development of contact karst have been investigated in detail.

Key words: contact karst, karst, alluvial fan, relict alluvial fan, Matarsko podolje.

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Uroš Stepišnik, Mateja Ferk, Petra Gostinčar, Luka Černuta, Karmen Peternelj, Tomaž Štemberger & Urša Ilič: Vršaji na kontaktnem krasu: primer iz Matarskega podolja, Slovenija

Na slovenskem krasu je več različnih tipov kontaktnega krasa. Najpogostejši je ponorni tip kontaktnega krasa, ki se navadno pojavlja med fliši in apnenci. Najdaljši kontakt te vrste v Sloveniji je na območju Matarskega podolja v zahodni Sloveniji, kjer se pojavljajo mnoge kraške kotanje, ki so značilne za kontaktni kras. Na severozahodnem delu Matarskega podolja se pojavljata dva tipa vršajev. En vršaj z aktivnim procesom sedimentacije rečnih nanosov na površju in ima obliko, ki je značilna za vršaje v fluvialnem geomorfnem sistemu. Drug tip predstavljajo reliktni vršaji na kontaktnem krasu. To so površinske oblike podobne vršajem na karbonatni matični podlagi. Njihov nastanek je vezan na postopno denudacijo rečnih naplavin na območjih, ki so jih prekrivali vršaji, in kemično denudacijo karbonatne matične podlage. Podrobneje so bile proučene geomorfne oblike in procesi na vršajih ter vpliv vršajev na razvoj kontaknega krasa.

Ključne besede: kontaktni kras, kras, vršaji, reliktni vršaji, Matarsko podolje.

INTRODUCTION

In Slovenia the most common form of contact karst is the ponor type of contact karst, where waters from a non-karstic catchment flow onto the karst surface. Such karst has developed where the non-karstic surface is at a higher elevation or where the hydraulic gradient of water is directed into the karst and is higher than the surface gradient (Mihevc, 1991).

Surface karst features typical of the ponor type of contact karst in Slovenia are blind valleys, ponor steepheads (Mihevc, 1991), trough valleys, karst plains (Gams, 2001) and collapse dolines (Stepišnik, 2006). Caves within contact karst contain allogenic rivers and have horizontal passages of epiphreatic origin (Gams, 2004). Ex-

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tensive sections of denuded horizontal caves have been found on the karst surface (Mihevc, 2001).

The aim of the research was a detailed investigation of aspects of a contact karst area in the northwestern part of the Matarsko podolje in western Slovenia, where four alluvial fans have been revealed. The article describes processes on contact karst in a specific hydrological situation, where alluvial fans occur. Development processes of contact karst alluvial fans and alluvial fan-like surface features in carbonate bedrock were studied in detail. The term relict alluvial fans is used to describe fan-like surface features in carbonate bedrock that are the result of denudational processes acting on alluvial fans on contact karst.

The research included detailed geomorphological mapping of the alluvial fans and the hydrological hinterland area. Longitudinal profiles of the fans and of the Podseč stream were measured in detail. Thickness of alluvium cover was established using Earth resistivity imaging. The SuperSting R1/IP earth resistivity meter developed by Advanced Geosciences, Inc. was used for data collection. Survey was conducted with a dipole-dipole array, with a 5m separation between electrode pairs. The data were processed to generate two-dimensional resistivity models using EarthImager 2D resistivity inversion software developed by Advanced Geosciences, Inc.

One of the fans is undergoing active alluvial sedimentation, and alluvial flysch sediment is covering the limestone bedrock, forming a typical fan-shaped landform in ground plan. The other three fans are relict. Those fans are not composed of alluvial material typical of fluvial alluvial fans, but they are fan-like surface feature in carbonate bedrock. They are situated in areas that were covered by non-carbonate alluvium of earlier alluvial fans. Alluvium has been denuded from the outer sections of the fans, and the process of karstification of the underlying carbonate bedrock has begun. The result of the gradual removal of the alluvial cover and chemical denudation of newly re-exposed carbonate bedrock is a typical longitudinal profile shape that is characteristic of relict alluvial fans. To date relict fans have not been mentioned in the karstological literature as being typical surface features of contact karst.

Mihevc (1991) established that the alluvial fans in the study area are a morphologically less distinct element of contact karst. On the basis of the alluvial cover on the karst and alluvial sediments in the doline floors in the lower sections of fans, he concluded that parts of fan-like features were also previously covered by flysch alluvium. According to Gams (2004), the formation of alluvial fans on karst is related closely to the colder periods of the Pleistocene, when accumulation of water-borne sediments related to physical weathering was more intensive. Gams established the term "pseudo-alluvial fans" to describe fans on karst that lack recent accumulations of alluvium on their surface.

AREA OF MATARSKO PODOLJE

The most distinctive example of ponor type contact karst in Slovenia is the Matarsko podolje area, in southwestern Slovenia. Matarsko podolje is a planated lowland area between the Brkini Hills in the northeast, the Slavnik Mountains in the southwest, the Karst plateau in the northwest and Brgudsko podolje in the southeast. It is elongated northwest–southeast, with a length of 18 km and a width between 2 and 3 km. The elevation in the northern part, near Kozina, is about 490 m and in the southeast, near Starod, the elevation is about 640 m (Fig.1).

The northeastern part of Matarsko podolje area is the contact between flysch of the Brkini hills and carbonate bedrock of Matarsko podolje. At the contact Eocene flysch bedrock overlies Palaeocene limestones, and away from the contact these give way to Cretaceous limestones, dolomites and limestone breccias. The dip of the beds is from 20 to 60 degrees towards the northeast (Pleničar *et al.,* 1975).

Matarsko podolje has the greatest lateral extent of all the ponor contact karst areas in Slovenia. The surface is relatively flat, and rich in dolines, large collapse dolines and caves. 24 allogenic streams sink at or near the contact between the flysch and the carbonate bedrock, forming such typical ponor karst features as blind valleys and ponor steepheads (Mihevc, 1991). Caves in the hinterland of the allogenic streams ponors are mostly vadose shafts, together with longer sections of relict and active horizontal epiphreatic passages. There are also more than 80 collapse dolines (Stepišnik, 2006) and numerous longer sections of sub-horizontal denuded caves on the karst surface.

Fig. 1: The location of the study area.
Sl. 1: Lega proučevanega območja.

ALLUVIAL FANS ON CONTACT KARST

The area studied in detail is situated in the northwestern part of the Matarsko podolje. In general it consists of three geomorphological units; a higher flysch area to the northeast, an area of active alluvial fan and three relict alluvial fans on the contact between flysch and limestone, and the karst plain of Matarsko podolje.

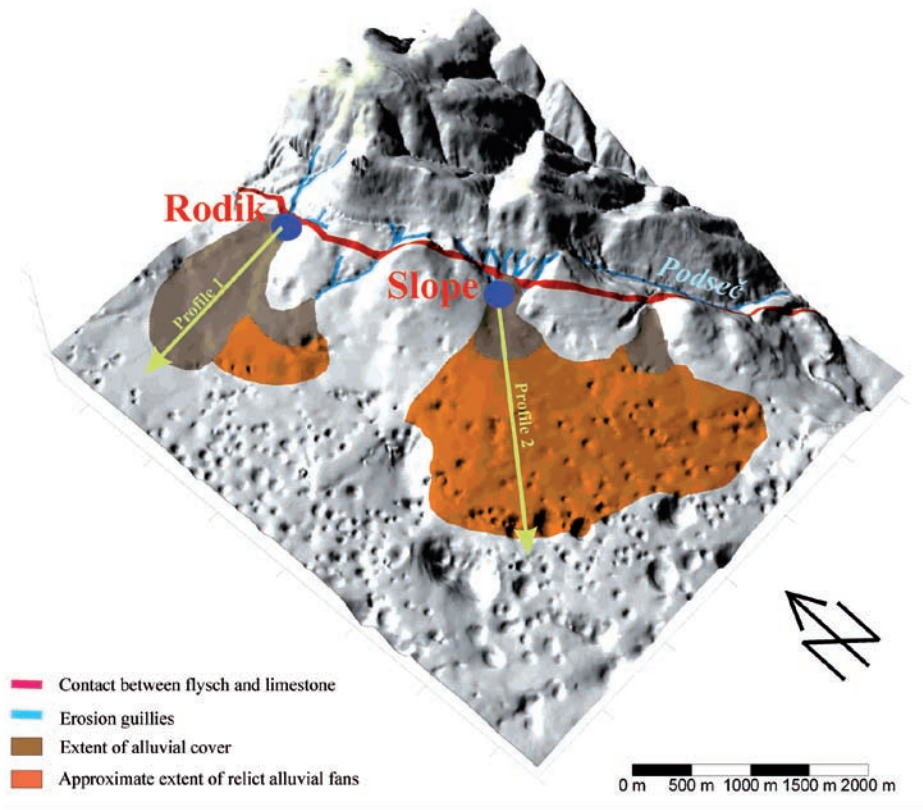

Fig. 2: Sketch of the alluvial fans area.
Sl. 2: Slika območja vršajev.

In the flysch area a fluvial geomorphological system is present, with many erosion gullies on the steep flysch slopes. The flysch crest in the area is 300 m higher than the lower karstified surface of Matarsko podolje. The feeder channels terminate at or near the contact between the flysch and limestone, where the apices of four alluvial fans are situated. Although water flow is only periodic at present, fan deposits cover the local area of Palaeocene and Cretaceous carbonate bedrock near the contact. The Podseč stream, which drains eastwards to the Brezvica

blind valley, has beheaded most of the feeder channels in the hinterland of the relict alluvial fans.

The studied alluvial fans lie along a 2.3 km section of the contact karst between the flysch and limestone bedrock. In the northwestern part of the area, near the village of Rodik, is an active alluvial fan covering an area of approximately 0.3 km^2. A smaller relict fan, with an area of approximately 0.18 km^2 is situated farther southeast. Near the village of Slope is an extensive relict alluvial fan about 1.14 km^2 in area. In the southeastern part of the study area a smaller relict fan, with an area of about 0.41 km^2, is situated at the bottom of the wide fossil valley of Bilendol (Fig. 2).

The only alluvial fan in the area is the fan near Rodik. From the flysch bedrock an erosion gully with periodic water flow extends on to the upper section of fan area. There are no karst features on the surface of the fan, which consists of flysch alluvium. The outer sections of the fan merge into the flattened karst surface, which is covered with surface karst features, that increase in density with distance from the fan. Grikes become bigger and their density increases, and dolines become greater in number, with steeper slopes. Near the outer sections of the fan are some sub-horizontal sections of cave passages, partly filled with flysch pebbles and loam. Those caves might have functioned as ponors for alluvial fan waters, so sediment fill and the morphology of the caves should be studied in detailed in the future.

In the area of the relict alluvial fans and their hinterlands are traces of relict erosion gullies and valleys. Most of the tributaries to the relict alluvial fans were beheaded by the Podseč stream, which now drains to the nearby Brezovica blind valley (Fig. 3). Comparison of an equilibrated longitudinal profile and the actual longitudinal profile of the Podseč stream reveals distinct anomalies in the area of beheaded fossil valleys and erosion gullies upstream of the relict alluvial fans.

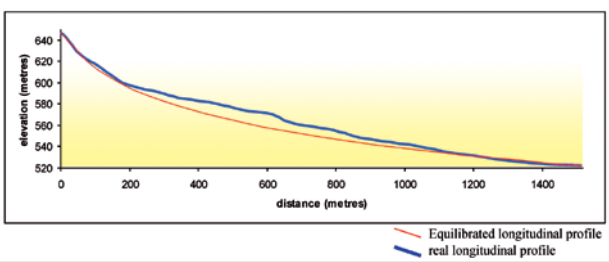

Fig. 3: Equilibrated and actual longitudinal profile of stream Podseč.

Sl. 3: Uravnotežen in dejanski podolžni profil potoka Podseč.

The upper sections of the three features that are defined here as relict alluvial fans are covered with flysch-derived alluvium from the Brkini hills. Carbonate bedrock is exposed on the central and outer sections of the fans and surface karst features such as grikes and dolines are present. Short sections of relict riverbeds are also apparent on the parts of the fan surface that are covered with alluvium. The outer and central sections of the fans are convex, whereas the upper sections are concave in longitudinal slope profile.

According to geomorphological texts, alluvial fans are river accumulation landforms that are cone-shaped in longitudinal profile and fan-shaped in ground plan. They are formed where feeder channels leave a narrow valley and enter a wider valley or plain. The velocity of the stream and its transportation capacity are decreased, and much of the load is deposited (Summerfield, 1996; Goudie, 2004). There are many sub-types of alluvial fan, according to their shape and age of development (Gams, 1964; Gams, 2001; Sauro, 2001; Goudie, 2004), but the sedimentation of alluvial fans is a specific process. The decrease in water flow velocity results in the deposition of larger sediment clasts in the upper sections and finer sediment in the lower sections. A typical alluvial fan has a concave longitudinal profile with a slope inclination of up to 10 degrees in its upper sections and from 1 to 5 degrees in its lower sections (Bull, 1977; Summerfield, 1996; Goudie, 2004).

As mentioned above, there are two types of alluvial fan in the study area. The first type is represented by a single fan undergoing active alluvial sedimentation near Rodik. The thickness and structure of the alluvium and the longitudinal profile correspond to alluvial fans of fluvial geomorphological systems. The upper section of the fan has an inclination of 4 degrees, with the inclination decreasing with increasing distance downslope from the upper section. The thickness of alluvium, established using electrical resistance imaging techniques, is more than 30 m in the upper section of the fan. The structure of the fan profile in this upper part consists of layers of gravel, sand and loamy material. The thickness of alluvium in the middle section of the fan is about 25 m and the slope of the longitudinal profile is gentler. The outer section of the fan is flattened and limestone bedrock is exposed; lower parts of the karst surface are covered with loamy alluvium. The surface of the underlying carbonate bedrock seems to be lower under the upper section of the alluvial fan, suggesting that the fan might cover a relict blind valley. This should be investigated in detail in the future.

Three alluvial fans of the second type, or relict alluvial fans on the karst, are situated near Slope. Their ground plan shapes are fan-like, but the longitudinal profiles are distinct in shape. Their upper sections are concave but in the middle and outer sections they become convex. The

slopes of the upper sections reach 7 degrees, whereas the middle sections are relatively flattened. Surface slopes in the outer sections of the fans reach up to 6 degrees. The thickness of the alluvium in typical active fluvial alluvial fans decreases with distance from the upper sections. Alluvial deposits cover only the upper sections of the relict alluvial fans, where their longitudinal profile is concave. The outer sections of the fans are convex in shape and the limestone bedrock does not have alluvial cover. The density of surface karst features increases with distance from the edge of the alluvial cover.

The characteristic longitudinal profile of relict alluvial fans of this type is a result of cessation of deposition of flysch-derived residual sediment in the fan area. Denudation effects on the residual cover appear to be less intense than those on the neighbouring karst surface where limestone bedrock is exposed. Thus, on alluvial fan surfaces that are covered with flysch-derived deposits lowering appears to be less rapid than on the adjacent fan-shaped karst surface. This difference in erosion rates results in the distinctive shape of the longitudinal fan profiles. These fans exhibit typical longitudinal profiles only in their upper sections, where thick alluvial cover is preserved. In the areas with denuded alluvial cover the dynamics of limestone bedrock corrosion are intense and thus surface lowering is also more intensive. Alluvial cover thickness diminishes with distance from the uppermost section of the fan, so the alluvial cover on the outer sections the fan will be the first to be denuded, exposing the bedrock to the process of corrosion. Subsequently, sediment will gradually be removed and carbonate bedrock will be exposed towards the upper sections of the fan, which results in development of a convex longitudinal profile where bedrock is exposed (Fig. 4).

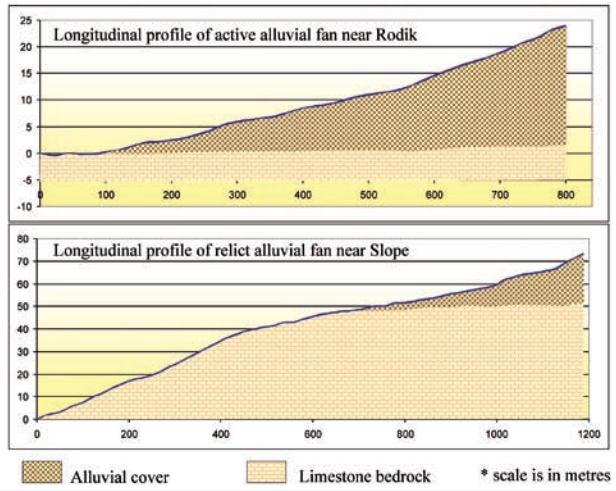

Fig. 4: Longitudinal profiles of the alluvial fans near Rodik and near Slope.

Sl. 4: Podolžni profili vršajev pri Rodiku in Slopah.

CONCLUSIONS

Detailed investigation of the contact karst in the northwestern part of Matarsko podolje revealed that the process of alluvial fan formation is in general the same on karst as in non-karstic fluvial geomorphological systems. An alluvial fan is concave in shape if the dynamics of sedimentation of the fan are greater than the dynamics of the sediment cover denudation. Where the sedimentation dynamics of the fan are lower or completely static the sediment cover is gradually denuded. The thickness of alluvial cover is lowest in the outer sections of the fans and thus the period of limestone bedrock exposure to chemical denudation will be longest in these areas. The result of this process is the formation of a convex longitudinal profile in the outer sections of relict alluvial fans. The final outcome, if all of the alluvial cover is denuded, is a geomorphic feature that is fan shaped in ground plan and convex in longitudinal profile.

The alluvial fans in this part of the Matarsko podolje have formed because the Brkini Hills stand high above the flat karst surface. Intensive erosional processes on the high ground resulted in generation of flysch debris and input of alluvial material to the karst. Due to the concentrated material input the waters deposit alluvial fans rather than forming blind valleys.

Relict alluvial fans embossed on the karst surface have not previously been interpreted as landforms typical of contact karst, even though the process of their formation is exclusively related to contact karst. The alluvial fans in the study area can be used as an example for the interpretation of alluvial fan formation mechanisms on other dynamic karst surfaces.

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POVZETEK

Najbolj značilen primer ponornega kontaktnega krasa v Sloveniji je Matarsko podolje, ki je relativno uravnana pokrajina med Slavniškim pogorjem in Brkini. Nahaja se v jugozahodnem delu Slovenije. Dolgo je 18 kilometrov, razpotegnjeno v smeri severozahod – jugovzhod, in sega od Kozine, kjer dosega nadmorsko višino okoli 490 metrov, do Staroda, kjer so nadmorske višine okoli 640 metrov. Širina podolja je od 2 do 5 kilometrov. Na jugovzhodu meji na nižje Brgudsko podolje, na severozahodu pa preide v Matični kras (Sl. 1).

Površinsko in podzemeljsko je Matarsko podolje zakraselo, v grobem je uravnano in prepleteno z velikimi udornicami, vrtačami in jamami. Na severozahodnem obrobju Matarskega podolja med fliši Brkinov in apnenci Matarskega podolja ponira 24 ponikalnic. Stik med fliši in apnenci je pogojeval nastanek niza večih slepih dolin in ponornih zatrepov (Mihevc, 1991). Med jamskimi rovi v zaledju slepih dolin prevladujejo brezna, ki so nastala v vadozni coni, ter daljši odseki fosilnih vodoravnih rovov.

Proučevano območje leži na skrajnem severozahodnem delu Matarskega podolja, med najvišjim severozahodnim delom flišnih Brkinov, pobočjem Videža na zahodu in uravnanim delom Matarskega podolja pri Kozini na jugu. Na severozahodnem delu je na flišnih kamninah izoblikovan fluvialni geomorfni sistem. Flišni greben je 300 m nad kraško uravnavo Matarskega podolja. Na strmih flišnih pobočjih so izoblikovani erozijski jarki, ki odvajajo vodo in flišno preperelino proti zahodu in jugozahodu na kraško površje. V erozijskih jarkih je voda prisotna le ob večjih količinah padavin. Erozijski jarki se končujejo na stiku eocenskih flišov in paleocenskih apnencev. Pod njimi so na območju razviti štirje večji vršaji, ki z nanosi prekrivajo paleocenske in kredne apnence Matarskega podolja (Sl. 2).

Proučevani vršaji so razporejeni na kontaktu fliša in apnenca v razdalji 2,3 km. Na severozahodnem delu območja pri naselju Rodik je vršaj s površino okoli 0,3 km^2. Jugovzhodneje se pod večjo erozijsko grapo, ki prečka greben paleocenskih apnencev, nahaja manjši vršaj s površino 0,18 km^2. Dalje proti jugovzhodu pri vasi Slope leži velik vršaj s površino 1,14 km^2. Na skrajnem jugozahodu se ob zaključku fosilne doline Bilendol nahaja manjši vršaj z velikostjo 0,14 km^2.

Na proučevanem območju se nahajata dva tipa vršajev, na podlagi katerih je mogoče tolmačiti razvoj teh

oblik kontaktnega krasa v dinamičnem kraškem površju. Prvi tip predstavlja vršaj pri Rodiku, na katerem je še aktivna sedimentacija alohtonega materiala. Ta vršaj po globini naplavine, velikosti delcev v naplavini, oblikovanosti podolžnega profila in tlorisni oblikovanosti ustreza vršajem v fluvialnem geomorfnem sistemu. Naklon v vrhnjem delu je največji in dosega do 4° ter se z oddaljenostjo od vrha vršaja zmanjšuje. Globina naplavine, ki je bila ugotovljena z meritvami profilov električne upornosti tal, v vrhnjem delu presega globino 30 m. V tem delu se v nanosih menjavajo plasti proda, peska in ilovnate prepereline. Globina nanosov v osrednjem delu vršaja je 25 m, prav tako se zmanjša tudi naklon. Ob koncu vršaja je površje popolnoma uravnano in ilovnati nanosi zapolnjujejo nižje dele kraškega površja.

Drug tip so reliktni vršaji na območju naselja Slope. Reliktni vršaji so le površinske oblike v karbonatni matični kamnini, ki so se razvili iz fluvialnih vršajev. V tlorisu so tipične pahljačaste oblike, v oblikovanosti podolžnih profilov pa se kaže dvojnost. Do osrednjega dela so v profilu konkavnih oblike, ki po uravnanem osrednjem delu preidejo v konveksne oblike. V zgornjih konkavnih delih nakloni dosegajo vrednost do 7°. V osrednjih delih so uravnani, v spodnjih konveksnih delih pa nakloni dosegajo vrednost do 6°. Debelina naplavine bi se teoretično morala zmanjševati z zmanjševanjem naklona. Pri tem tipu vršajev preperelina prekriva le zgornje, konkavne dele, medtem ko v spodnjih konveksnih delih prepereline ni, oziroma se na površju pojavlja le izjemoma. V spodnjih konveksnih delih vršajev so razvite površinske kraške oblike, kot so škraplje in vrtače. Gostota površinskih kraških oblik narašča z oddaljenostjo od fluvialne naplavine, ki prekriva zgornje dele vršajev.

Na območju reliktnih vršajev in njihovem zaledju je večje število erozijskih jarkov in fosilna dolina. Večina pritokov na reliktne vršaje je bila obglavljenih s potokom Podseč, ki odvaja vodo proti jugovzhodu v smeri slepe doline Brezovica. Primerjava podolžnega profila in uravnoteženega podolžnega profila potoka Podseč, kaže izrazito nepravilnost v območju podolžnega profila, ki leži v bližini območja reliktnega vršaja pri fosilni dolini Bilendol (Sl. 3).

Dvojnost podolžnih profilov reliktnih vršajev je nastala zaradi prekinitve procesa akumulacije fluvialnih sedimentov na vršaje. Oblika podolžnega profila reliktnih vršajev kaže na to, da je dinamika procesa denudacije flišne prepereline manjša od dinamike denudacije okoliškega kraškega površja, zato se na območjih vršajev, ki jih prekriva flišni nanos, površje znižuje relativno počasneje. Proces se postopoma nadaljuje proti vrhnjemu delu vršaja. Posledica je izrazita konveksna oblikovanost v spodnjem delu podolžnega profila vršaja (Sl. 4).

Na podlagi podrobnega proučevanja vršajev v severozahodnem delu Matarskega podolja lahko zaključimo, da je proces oblikovanja vršajev na krasu v grobem enak kot na fluvialnem geomorfnem sistemu. Dokler je dinamika nanašanja materiala na vršaj večja ali enaka dinamiki denudacije akumuliranega materiala, bo vršaj ohranil tipično konkavno obliko. V primeru, da je nanašanje manjše ali pa da se popolnoma ustavi, bo nanesen material, ki prekriva kraško površje, postopoma denudiran. Najmanjša debelina nanosov je na robovih vršaja, zato bo kraško površje tam najprej izpostavljeno kemični denudaciji. Ker je dinamika kemične denudacije kraškega površja večja od denudacije flišnih nanosov, ki prekrivajo apnence, se površje ob koncu vršajev hitreje znižuje, kar ima za posledico konveksno obliko spodnjega dela fosilnega vršaja. V skrajni obliki, ko je denudiran celoten alohton material vršaja iz kraškega površja, ostane površinska oblika na kontaktnem krasu, ki je v tlorisu pahljačaste oblike, v profilu pa je konveksna.

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TURLOUGHS: A MOSAIC OF BIODIVERSITY AND MANAGEMENT SYSTEMS UNIQUE TO IRELAND

TURLOUGH: MOZAIK BIOLOŠKE RAZNOVRSTNOSTI IN NAČIN GOSPODARJENJA, EDINSTVEN ZA IRSKO

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Abstract UDC 911.2:556.166(417)

Sheehy Skeffington M. J. & Gormally, M.: Turloughs: a mosaic of biodiversity and management systems unique to Ireland

Turloughs are seasonally flooded karst wetlands in Ireland and as priority habitats under the EU Habitats Directive, many have been designated as Special Areas of Conservation. They flood usually in winter, mostly through swallow holes, or estavelles, that open to the underlying limestone, but they may fill at any time of year if rainfall is excessive. Almost all of them occur on well-bedded pure Carboniferous limestone.

Since the shallow basins of turloughs are usually covered in vegetation, unlike more permanent water bodies, they are excellent feeding areas for over-wintering wildfowl, such as ducks, geese and swans, hosting numbers of international importance. Turloughs are almost all grazed by domestic livestock in the summer months and they support relatively low-intensity farming due to their marginal nature and inaccessibility for much of the year. The vegetation depends to a large extent on the flooding regime and on soil type, usually comprising small-sedge communities or grass-dominated swards. The type of management varies considerably, not only between, but within turloughs. This gives rise to a diversity of sward composition and structure that increases both plant and invertebrate diversity. Whereas drainage was a large threat to turlough conservation in the past, eutrophication of flood waters is gaining in importance. However, the single greatest threat to turlough biodiversity in the future may be the cessation of farming within their basins. Turloughs are an integral part of the Irish cultural landscape and so it is important to develop a strategy for turlough conservation that involves the land-owners and takes into account local socio-economic factors as well as the conservation of their biodiversity.

Key words: turloughs, wetland, seasonal flooding, biodiversity, management, grazing, Ireland.

Izvleček UDC 911.2:556.166(417)

Sheehy Skeffington M. J. & Mike Gormally: Turlough: mozaik biološke raznovrstnosti in način gospodarjenja, edinstven za irsko

Turlough je sezonsko poplavljeno mokrišče na Irskem in kot prednostni habitat pod EU Direktivo za habitate. Številni turloughi so tudi označeni kot Posebno varstveno področje. Turloughi so običajno poplavljeni pozimi, voda jih zalije skozi požiralnike – estavele, ki se odpirajo v podlagi iz apnenca. Če je dežja preveč, se lahko napolnijo z vodo ob kateremkoli letnem času. Skoraj vsi so na plastovitem karbonskem apnencu. Ker so te plitve kotanje ali turloghi običajno porasli, medtem ko stalna vodna telesa niso, so izvrstna pasišča in krmišča za prezimujoče vodne ptice, kot so race, gosi in labodi, katerih število je mednarodno pomembno. Skoraj vsi turloughi so v poletnih mesecih pašniki za živino, a le v okviru ekstenzivne reje, saj so obrobnega pomena in velik del leta nedostopni. Rastlinstvo je v veliki meri odvisno od poplavnega režima in tipa prsti; v glavnem gre za skupnost malega šaša ali za travnike. Način gospodarjenja je zelo različen, ne le med posameznimi turloughi, ampak tudi na posameznem turloughu. Zaradi tega so nastali zelo različni travniki, tako po sestavi kot po strukturi, kar pospešuje tako rastlinsko raznovrstnost kot tudi raznovrstnost nevretenčarjev. Medtem ko je bilo osuševanje nekdaj največja nevarnost za turloughe, postaja danes najpomembnejša evtrofikacija poplavne vode. Vendar pa bo v bodoče največja grožnja biološki raznovrstnosti teh kotanj prenehanje njihove izrabe v kmetijske namene. Turloughi so sestavni del irske kulturne pokrajine in je torej pomembno določiti ukrepe za njihovo ohranitev, ki bodo vključevali lastnike zemlje in upoštevali tako družbenoekonomske dejavnike kot tudi ohranjanje njihove biološke raznovrstnosti.

Ključne besede: turlough, mokrišče, sezonska poplava, biološka raznovrstnost, gospodarjenje, paša, Irska.

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INTRODUCTION

Turloughs are karst basins that occur where Carboniferous limestone is exposed or near the surface and where, with high rainfall, groundwater eventually flows out into the basin through springs or estavelles (swallow holes that also act as springs) (Coxon 1987a, b). Turloughs are relatively shallow basins, a majority flooding to 1-3 m depth in winter (Coxon 1987b). They support vegetation and/or soils characteristic of wetlands (Working Group on Groundwater 2004). The limestone in which they occur is almost always a very pure Dinantian bedded limestone (Sheehy Skeffington *et al.* 2006). They are a feature of Ireland as not only are there extensive areas of low-lying exposed limestone, but high rainfall (>1,000mm in the western 2/3 of the country) falls throughout the year (>150 rain days per year) (Collins & Cummins 1996). Turloughs fill mostly in the winter months (October to April), but may also fill during times of persistent heavy rainfall, as in August-October 2001 (Moran *et al.* 2000) and May 2006.

Since most turloughs drain for at least 5 months during the summer, the basin floors support a range of plant communities, from dry grassland at the edge to wetland communities in the main basin and aquatic vegetation in wetter turloughs (O'Connell *et al.* 1984; Goodwillie 1992, 2003). The summer-accessible grassland has long been valued as pasture, and grazing by domestic stock is likely to prevent encroachment by scrub in the upper reaches of the basin, whereas flooding prevents trees from spreading to the centre (Praeger 1932; Goodwillie 2003). The name is an Irish term and opinions differ concerning its origins, but here we follow that suggested by Joyce (1869), with –lough as a corruption of the suffix –lach (the current Irish spelling is turlach) that would mean the word refers to a place that dries out (tur = dry), not a 'dry lake' (lough means lake). This interpretation puts greater emphasis on the fact that the place dries out. This is in keeping with the fact that any such place would have always been valued for use as summer pasture.

Turloughs are almost unique to Ireland (there is one in Wales - Campbell *et al.* 1992) and have priority status under the Habitats Directive (EEC 1992). A total of 71 turloughs have SAC status and nine of these are also SPAs, as many turloughs are important winter feeding habitats for wildfowl that benefit from the full vegetation cover under the shallow water (Ruttledge 1989; Cabot 1999; Sheehy Skeffington *et al.*, 2006). A large proportion of the whooper swans *Cygnus cygnus* which overwinter in Britain and Ireland can be found on turloughs (Robinson *et al.* 2004).

Turloughs vary in size from 1 ha or less to over 250 ha. Whereas many of those > 10 ha have been described in detail, including their area, (Coxon 1987a, b; Goodwillie 1992), many more exist that are smaller than this. To date over 300 active turloughs have been documented and the size of about 100 is known (Goodwillie *et al.* 1997; Sheehy Skeffington et al. 2006). Of these, the biggest number are < 10 ha and many more fall within the 20-40 ha size category (Fig. 1). However, it is likely that a majority of those for which the size is not known are <10ha, since, due to their small size, they have not been fully documented. Following drainage schemes from the end of the 20th century, only one turlough larger than 200ha remains. Originally the biggest turlough was Turloughmore (which means 'big turlough') which extended to approximately 400 ha (D'Arcy 1983).

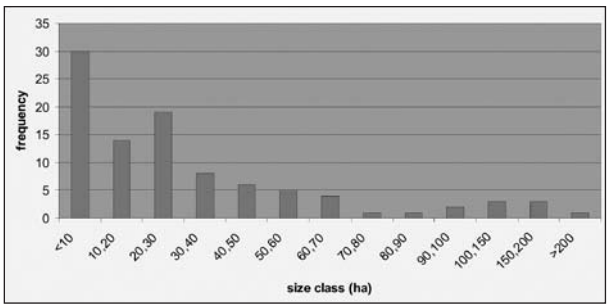

Fig. 1: Turlough size for 97 turloughs for which the area is known. Data from Goodwillie et al. (1997) and Sheehy Skeffington et al. (2006).

The plant communities of turloughs are relatively well documented (Goodwillie 1992; Goodwillie *et al.* 1997; Goodwillie 2003) and they usually form concentric zones around the turlough basin as a function of depth and duration of flooding (*Fig. 2* and also Moran *et al.* 2008). A total of 24 main plant communities have been described for the turloughs surveyed (Goodwillie 2003), which can be classified into two major phytosociological classes, the Scheuzerio-Caricetea fuscae, and the Plantaginetea majoris (Ivimey-Cook & Proctor 1966; O'Connell *et al.,* 1984). The occurrence of the former (usually sedge-dominated communities) is associated with greater soil moisture and peat formation, whereas the latter is characterised by grasses and species such as *Potentilla anserina* and predominates on more mineral soils (O'Connell *et al.* 1984; Ní Bhriain *et al.* 2002; Regan, *et. al.,* 2007, Moran *et al.,* 2008).

To date, most ecological research on turlough invertebrates has been on the aquatic communities (see e.g. Reynolds 1996; 2000; 2003) and the terrestrial turlough invertebrates have received only sporadic attention (see, however, Owen 1997; Good & Butler 2001; reviewed in

Sheehy Skeffington *et al.,* 2006). But the salient results of this research indicate that turloughs harbour a number of rare terrestrial invertebrate species and that the aquatic communities, due to the ephemeral nature of the habitat, are also unusual, if relatively species-poor. The rarity of the invertebrates is partly due to the disappearance in Europe of wetland habitats, whereas Ireland still retains a large proportion of relatively intact wetlands (EEA 2004a). But crucial to their conservation is also the relative low-intensity of land use, not only on turloughs, but of the adjacent land (Good & Butler 2001; Bond 1997). In recent times, therefore, focus has been on the relationship between turlough land use and plant and invertebrate communities (Ní Bhriain *et al.,* 2002, 2003; Moran 2005; Regan 2005; Ryder *et al.,* 2005).

TURLOUGHS AS CULTURAL LANDSCAPES

With current reforms of the EU Common Agricultural Policy (CAP), there is an increasing need to be aware of their effects on the farming community in so-called 'marginal' lands. Such farming practices are extensive, with high labour but low chemical or mechanical inputs. These practices are not only intrinsically part of any national heritage, they are vital for the conservation of plant and invertebrate communities and even birds that feed on them (Bignal & McCracken 1996; EEA 2004b). As Ireland will lose its Objective 1 status in 2007, it is important to set up ways of encouraging farmers to remain on 'marginal' land, including turloughs, before that knowledge is lost or the land is abandoned.

Turloughs have mostly been managed as pasture, though in times of need they have been used for tillage (Aughney & Gormally 1999), occasionally with small plots for potatoes. Former cultivation ridges are still found around the margins of turloughs today. The whole system of turlough management can be seen on the old (1870s) 6 inch to a mile (1:10560) maps, where all the field boundaries are visible. Around turloughs, these generally form a pattern radiating out from the centre of the turlough basin (Fig. 2). In many cases, the central basin is managed as commonage with land-owners adjacent to or near the turlough having grazing rights. These rights can either relate to an exact amount of stock (grazing units in Ireland are sometimes known as 'collops', approximately equivalent to Livestock Units (1L.U. = 1 horse or adult cow)), or more commonly, it is agreed informally amongst the shareholders, who generally know the relative amount of stock their particular turlough can support.

Most land-owners graze cattle (dairy and beef animals) on turloughs (Aughney & Gormally 1999) but sheep are also found, as are horses, donkeys and even domestic geese (Feehan 1998; Aughney & Gormally 1999). Too early use of the turlough after the flood recedes, especially with heavy animals, is avoided, as this causes much poaching and damage to the vegetation. However, trampling and bare ground, with associated ruderal plants, are often a feature especially of the turloughs on more mineral soils (Goodwillie 1992; 2003).

For many turloughs, most local land-owners have land immediately adjoining the commonage, with the fields radiating out from the central basin (Fig. 2). In turloughs where there is no commonage, individual fields stretch right across the basin, traversing several flood zones and therefore vegetation bands (e.g. Moran *et al.,* 2008). The reason for this pattern of land use is connected not so much with an equal distribution amongst the community of land and vegetation type, but with the ready accessibility of water. This was particularly important before the advent of rural water schemes in Ireland in the 1950s, as the supply of water for stock was difficult. Farmers still ferry large containers of water from a turlough to stock, while water is still present in the turlough basin.

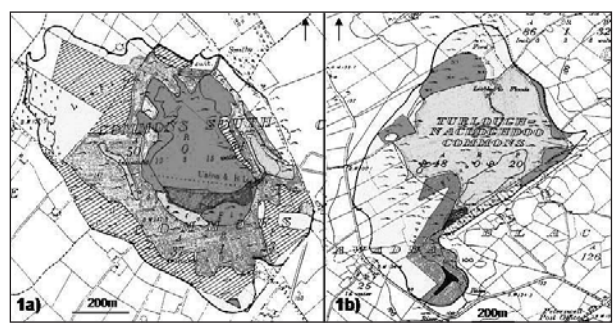

Fig. 2: Two turloughs in counties Longford and Galway showing vegetation patterns relating to flood duration. 1a) the entire basin is commonage, with fields radiating out from it; 1b) part of basin is commonage, the other part consists of radiating fields. Maps with permission from Goodwillie (1992).

The pattern of land use is primarily a function of flooding period (hydroperiod) with a farmer letting stock out onto the turlough as the flood subsides. The lower edge of the winter fields is usually the median upper limit of winter flooding (Fig. 3: the SAC boundary between the sets of fields in the southern part of the turlough follows

Fig. 3: Ballinacourty turlough in SE Galway, indicating fields radiating out from central basin. Each field is numbered according to land ownership, where each number refers to a different owner/ farmer. The fields to the NW (of which the turlough ones are marked '2') were originally those of the local land-lord and are therefore bigger. The dark line, outlining the main turlough basin and some of the fields, represents the SAC boundary. The central basin is made up of two commonages. Some walls are no longer functional, though their outline is visible. Aerial photograph by permission from Ordnance Survey, Ireland, Government of Ireland, Copyright Permit no. MP004506.

this). Access through this wall or hedge is usually via a gate to the adjacent high water for drinking. These fields provide grazing with water access through the times of highest flood (usually November-February). In exceptionally high flood, the lower portion of the field can be flooded, reducing the area of available grass, but continuing to supply water. As the flood subsides through the fields in the inner basin (through May), the stock can be let out onto these and a similar system of walls may exist to keep them from the central basin –which may be commonage (Fig. 3: inner walls of fields in S and SW part of turlough divide them from the commonage). In some cases, farmers have dug a pit in the lower end of this field, thus providing water without allowing the stock into the commonage.

CONSERVATION THROUGH MANAGEMENT

In the past, almost every field around a turlough was owned by a different farmer and still today different farmers will own adjacent fields in the turlough basin *(Fig. 3)*. What is even more striking is that each farmer frequently manages his/her fields in a different way (Feehan 1998; Ní Bhriain e*t al.* 2003). Not only does the stocking density vary, but the time and frequency of putting the stock out in the fields can be as varied as the number of farmers owning the fields (Ní Bhriain *et al.* 2003). The resultant heterogeneity in plant species composition and vegetation structure is very important for the diversity of invertebrates in the turlough (Ní Bhriain *et al.,* 2003; Moran 2005; Regan 2005).

This variety of land use within and between turlough basins is an important contribution to the biodiversity of turloughs. Thus the drawing up of management plans must take cognisance of the varied farming practices within and between turloughs and it is not possible to formulate generalised prescriptions for turlough management. Management plans need to be site specific, or there needs to be flexibility within any scheme, such as SAC prescriptions, that will allow for the individual farmers to continue their particular method of farming.

In addition, invertebrates and birds respond differently from vegetation to habitat conditions and management on turloughs and it is also necessary to bear this in mind when evaluating turloughs for conservation value. The vegetation can give an initial reference point for evaluation, but it must be followed up with more detailed surveys. In fact, evidence shows that it is important to conserve a range of sites, with a range of management systems, in order to cater for the diversity of organisms that benefit from turloughs.

THREATS TO TURLOUGHS

As with many wetlands, the main threat to turloughs is that of drainage and many have been lost in the past through this action. Drainage of Irish karst lowlands for over a century has lowered water tables and dried out turloughs, resulting in the loss of at least 50% of flooded turlough area (Drew & Coxon 1988). Although there is an on-going issue with farmers wishing to drain land, the decline in the importance of agriculture means that

such drainage schemes may now be less of a threat. Pollution and eutrophication are now becoming of increasing concern. In karst systems, groundwater is easily contaminated and difficult to trace, yet requires addressing under the Water Framework Directive (Working Group on Groundwater 2004). There is some evidence of catchment pollution, but also more intensively managed turloughs seem to support mesotrophic grassland, rather than the Cyperaceae-dominated swards of oligotrophic turloughs (see Sheehy Skeffington *et al.,* 2006).

However, another threat to turlough biodiversity, if not conservation per se, is the possible cessation of small-scale traditional farming in the west of Ireland. It is becoming increasingly clear that high nature value farmland is associated with so-called marginal land and that unless policies are devised to retain the farming community on the land, these areas will become abandoned (EEA 2004a). As most of the diversity of turloughs is intrinsically linked to the diversity of farming systems both within and between turloughs, it is important that they be included in any national plan to address high nature value farmland and its conservation. It is clear that turloughs are integrated into the human landscape yet their abandonment in favour of exploiting more accessible lands is a real possibility unless national policies specifically target them for conservation.

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DEGRADATION OF DOLINES ON LOGAŠKO POLJE (SLOVENIA)

DEGRADACIJA VRTAČ NA LOGAŠKEM POLJU (SLOVENIJA)

Mateja BREG[1]

Abstract UDC 551.435.8:551.44(44)

Mateja Breg: Degradation of dolines on Logaško polje (Slovenia)

As an example of long-term human intervention onto karst geomorphology, the article deals with the area of the Logaško polje, where degradation processes of dolines have been very intense during the last fifty years. The analysis of aerial photographs from different periods (years 1944 and 2000) was carried out on a study area of 604 ha. It showed that 77.5 % of dolines (441 of total 569) have completly disappeared mostly by being filled up with different waste materials (excavation material, municipal, industrial and building waste etc.) or they were built up while 22.5 % (128) of dolines have been entirely or partly preserved. Several anthropogenic factors that had an important influence on doline-changes are being evaluated. Despite the fact, that doline is a typical geomorphological feature in karst landscape the public (local or state) and the scientific sphere pay little attention on their geomorphological preservation and protection. Considering the paradigm of sustainability, the landscape and its landforms, as they are part of Earth's surface, would need to be classified as a non-renewable natural heritage or even non-renewable natural resources.

Key words: geography, doline, non-renewable natural resource, degradation, protection, sustainable development, Logaško polje, Slovenia.

Izvleček UDK 551.435.8:551.44(44)

Mateja Breg: Degradacija vrtač na Logaškem polju (Slovenija)

Kot primer dolgotrajnih antropogenih posegov v kraško geomorfologijo je v članku predstavljeno Logaško polje, na območju katerega je zadnjih petdeset let potekala zelo intenzivna degradacija vrtač. Na 604 ha velikem vzorčnem območju izvedena analiza letalskih posnetkov iz različnih obdobij (leto 1944 in 2000) je pokazala, da je 77,5 % vrtač (441 od skupno 569) popolnoma izginilo. V glavnem so bile zapolnjene z različnim odpadnim materialom (izkopni material, komunalni, industrijski in gradbeni odpadki) ali pozidane, 22,5 % (128) vrtač je bilo le delno pozidanih in preoblikovanih oziroma so se povsem ohranile. Ovrednotili smo številne antropogene dejavnike, ki so pomembno preoblikovali vrtače. Kljub temu da je vrtača tipična geomorfološka oblika kraške pokrajine, se tako v javni (krajevni ali državni) kakor strokovni sferi premalo pozornosti posveča njihovemu ohranjanju in zaščiti. Ob upoštevanju paradigme sonaravnega trajnostnega razvoja je treba pokrajino in reliefne oblike kot del zemeljskega površja opredeliti kot neobnovljivo naravno dediščino oziroma kot neobnovljiv naravni vir.

Ključne besede: geografija, vrtača, neobnovljiv naravni vir, degradacija, zaščita, sonaravni razvoj, Logaško polje, Slovenia.

INTRODUCTION

Landforms are among the most widely-spread and spectacular natural, non-biological features: dolines, river gorges, mountain peaks, natural bridges, maritime cliffs and others. They have always raised attention as attractive elements of the landscape but not only does the visual aspect of the landscape determine the importance of landforms, so does its cultural role. Besides that, the scientific, educational and research aspects have to be considered as well (Panizza and Piacente, 2003 in: Panizza, 2003).

While using natural resources man has for centuries selfishly subdued landscape and nature and transformed

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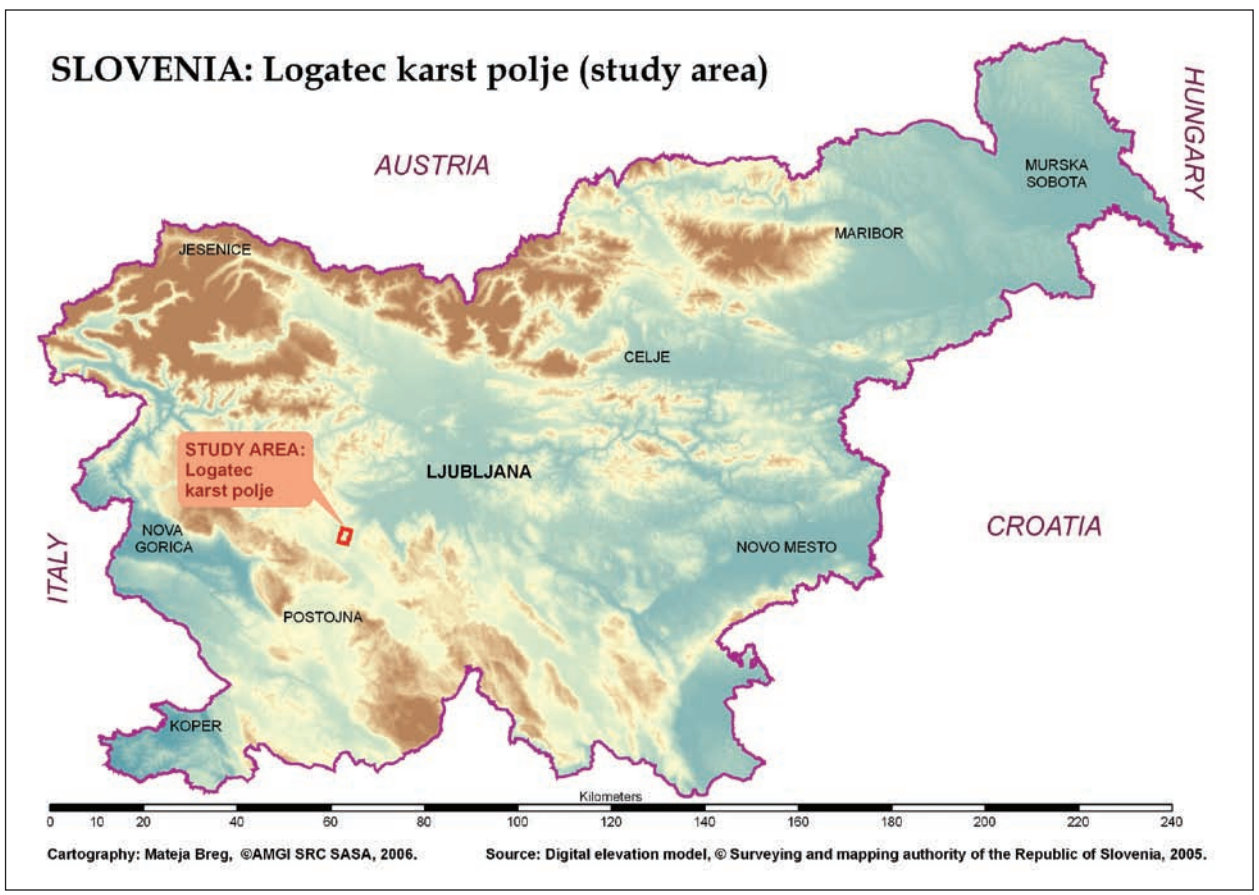
them in accordance to his needs. Cultivated dolines have been the site of various traditional activities (arable farming, gardening, pasturing, water supply etc.). In some Slovene areas (Kras, Bela krajina, Matarsko podolje etc.) these activities have survived to a smaller extent while in other places subtle cultural elements, such as dry-stone walls, speak of their past presence. Despite the apparent usefulness of dolines there had often been a desire among the inhabitants of karst regions, particularly in agricultural areas, to fill them up.

Many dolines today are filled up with different kinds of unknown waste material, covered with variable thick layers of cover-material or simply overgrown by vegetation. Waste materials (municipal, construction, industrial waste etc.) deposited in nature represent the most irresponsible activity affecting the karst features and processes that at one point became subject to degradation processes that had not only had a great effect on karst hydrology or ecology but also permanently influenced karst landforms and the entire landscape.

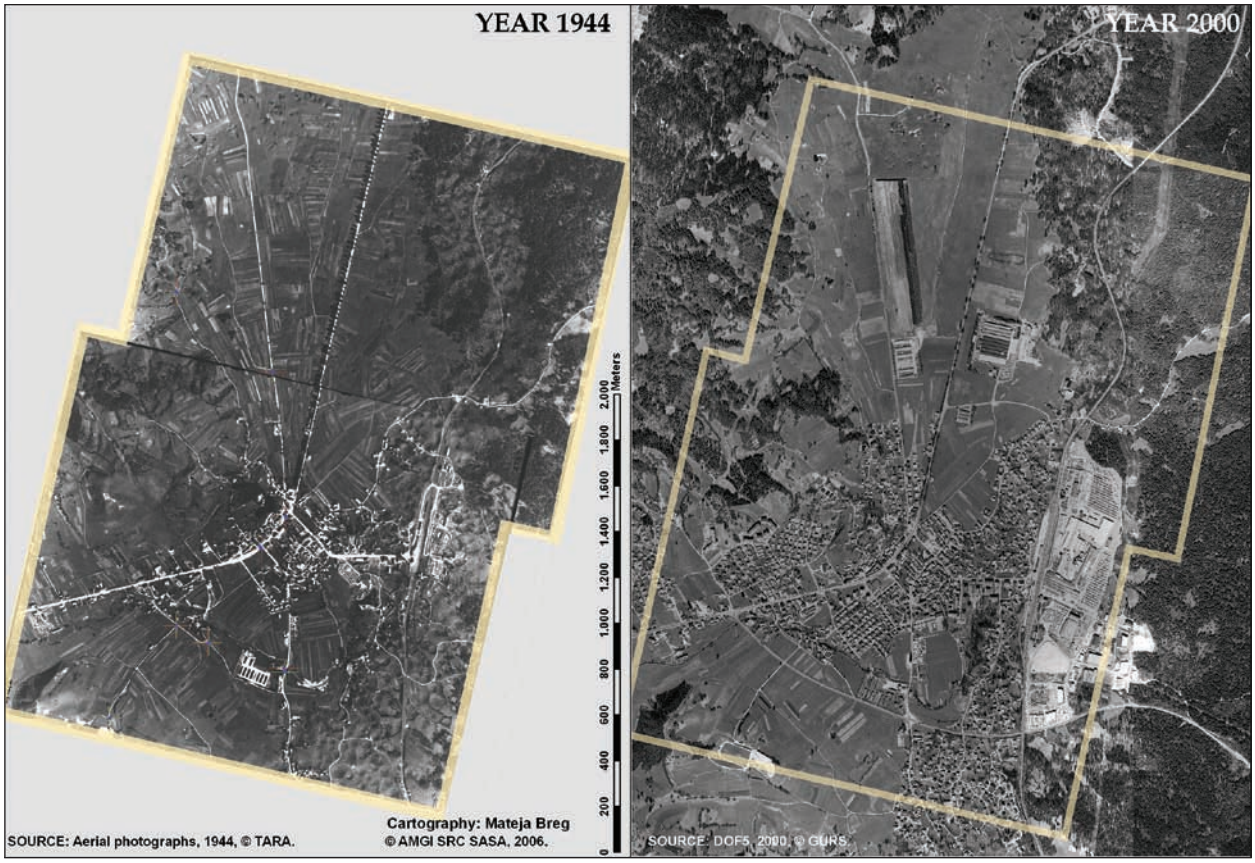
STUDY AREA AND WORKING METHODS

We have studied the North-East part of Logaško polje (map 1) where several dolines had been formed mainly on limestone bedrock (dark-grey limestone and grained dolomite) and river or stream deposits (Buser *et al.*, 1967). At the moment, the Logaško polje is under the biggest environmental pressure as several socio-spatial factors (proximity of Ljubljana, good transport connections, lower rents etc.) have caused immigration to its largest urban centre, Logatec (7616 inhabitants (SURS 2002)), and its surroundings. Furthermore the proximity of the motorway and a double track railway have stimulated the development of the secondary and tertiary activities and the expansion of the business-industrial zone.

The comparison of available aerial photographs from different periods can show how unsustainable the dealing with dolines had been over the last decades. The



Map 1: Logaško polje is located in the south-western part of Slovenia.



Map 2: Aerial photographs of study area in the years 1944 and 2000.

artificially defined test-area measures 604.8 ha (6.048 km²) and coincides with the surface of two partly covering digital b/w aerial photographs from 1944 (spatial resolution 1200 dpi). Archive aerial photographs from 1944 are the oldest known aerial photographs of the studied area and represent the starting point for the analysis of dolines-changes till the year 2000. The origins of the aerial photographs from 1944 are allied aerial observations during World War II. The documents are being kept in The Aerial Reconnaissance Archive (TARA) - University of Keele in the United Kingdom. The records are available in digital form but need to be georeferenced and their quality (colour, contrast, transparency) adjusted to get as much useful information as possible.

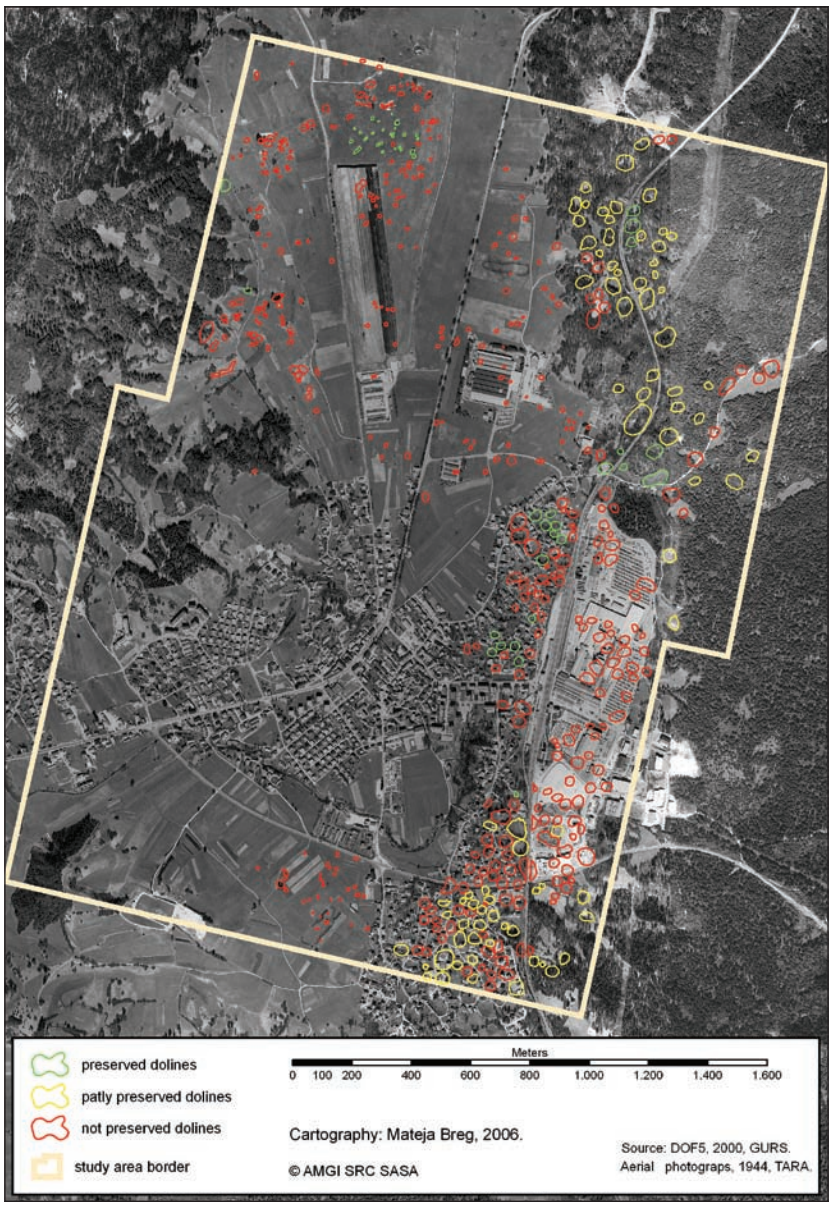
We have georeferenced the aerial photographs and adjusted them with the coordinate system DOF5 (Digital orthophoto image, scale 1 : 5000, Gauss-Krüger coordinate system). Based on selected old and new control point coordinates (buildings, junctions etc. that are present on both photographs) the computer program calculates the transformation parameters. The function contains formulas of linear mapping, un-linear mapping and the least squares method (Petek, Fridl, 2004).

The photointerpretation of the old aerial photographs and of the recent digital orthophoto (map 2) made it possible to digitalize the dolines (polylines) of the studied area at two points in recent history. The database was edited with separate attributes for each photograph. The identification of dolines and their main characteristics was based upon a photointerpretation-key that included following parameters: shape, depth (shadows give an impression of depth), colour (different shades of grey - the darker ones usually mark the bottom of dolines), texture. Attributes for each doline were defined with the help of visual photointerpretation and analysis. For the year 1944 the location, shape and dimension of each visible doline were determined and at the same time their actual presence was checked on the more recent photograph from the year 2000. Both sources served furthermore for identifying accessibility and land use of dolines. The gained data was statistically analysed.

CHANGES OF THE NUMBER AND LAND USE OF DOLINES IN THE LAST FIVE DECADES

On the aerial photograph from 1944, 569 dolines were evidenced and their shape, dimension and surface-cover determined. The spatial spread of dolines in the studied area is connected to its geologic structure: on limestone, dolines are larger and more concentrated, on fluvial deposits they tend to be smaller whereas there are almost none in the areas with dolomite bedrock. Dolines cover approximately 28.9 ha (0.288 km²), which represents 4.8 % of the total surface of the studied area. The average dimension of a doline is 507 m². The comparison shows that between the years 1944 and 2000 77.5 % of dolines (441 of total 569) have completely disappeared - in most cases they were being filled up with different waste materials (excavation material, municipal and building waste etc.) or they were simply built up. Furthermore 22.5 % (128) have been entirely or partly preserved (partly built up).

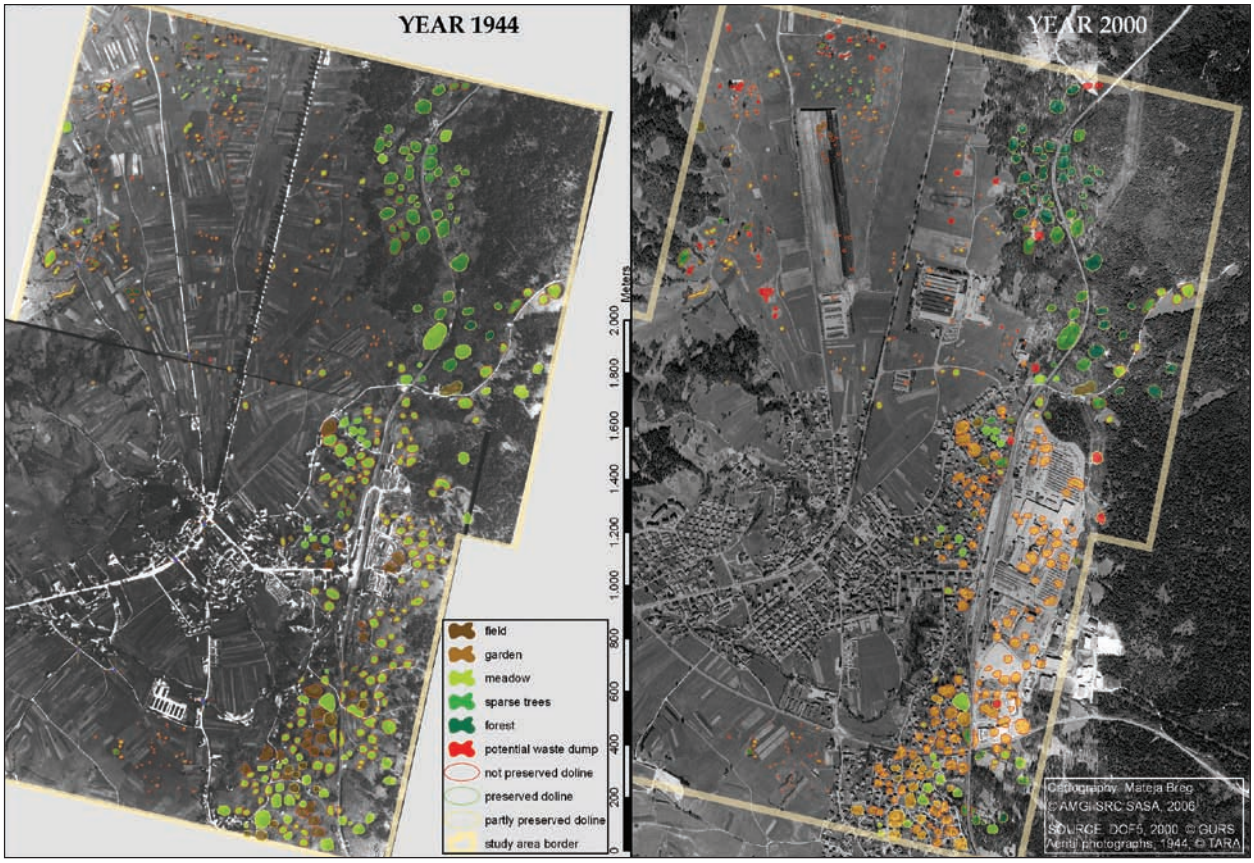
On map 3 red polygons mark the dolines which have not been preserved between the years 1944 and 2000, yellow polygons mark the partly preserved dolines and green polygons mark the preserved ones.



Map 3: Dynamics of the dolines-changes in the period 1944 – 2000.

Among the first to change the surface morphology were farming activities, most notably agriculture. The most important were agro-technical operations that were carried out in the lower part of the Logaščica stream basin in the year 1986 and continued in years 1987/88 on Pusto polje (in English: Bleak (empty) field). The prevailing process, that changed the landscape-morphology, was the filling up of dolines with soil, rock- and excavation material from other locations. For this purpose 12,000 m³ of material from an old railway embankment, dating from World War I, was used. At the same time municipal landfills in dolines, including industrial landfills with dangerous waste, were being covered (Bricelj, 1988).

The agricultural use of the doline's floor is conditioned by its shape and depth that defines the possible cultivation. Dolines covered with meadows (meadow-dolines) are usually cultivated in its entirety (bottom and slope) while the fields are usually located on the bottom of dolines and their flatter parts respectively. Field-dolines are best used if filled up and levelled to the surrounding height. Since the floor of dolines is mostly narrow the fields there are smaller, so in order to increase the arable land, dolines were filled up. A field on a greater surface consequently enabled a greater har-



Map 4: Land use in dolines in the years 1944 and 2000 regarding doline preservation.

	YEAR 1944				YEAR 2000			
Land use type in doline	*Number of dolines*	*Percent (%)*	*Area (m^2)*	*Percent of area (%)*	*Number of dolines*	*Percent (%)*	*Area (m^2)*	*Percent of area (%)*
Field	40	7	38,921	13	19	3	6,202	2
Forest	5	1	3,454	1	39	7	42,617	15
Meadow	448	79	186,050	64	230	40	52,965	18
Garden	1	0	669	0	9	2	5,238	2
Sparse trees, overgroving	73	13	59,510	21	41	7	40,215	14
Potencial waste dump	2	0	160	0	74	13	15,046	5
Built up, partly built up	0	0	0	0	154	27	125,146	43
Other	0	0	0	0	3	1	1,337	0
sum	569	100	288,765	100	569	100	288,765	100

Tab. 1: Land use in dolines in the years 1944 and 2000 (regardless the number and area).

vest. In the year 1944 the dolines coverd with fields (field-dolines) reached 7 % (40 counts) that represented 13 % of the total doline-surface.

The most common and the greatest were meadow-dolines as they represented 80 % of the dolines (448 counts) and 40 % of the total surface (186,050 m^2). Because the surface of a hemisphere is greater than the surface of a circle, meadows were economically more suitable and profited best from the available surface of the doline's concave structure. Grass can grow on the bottom and slope where the soil is thinner and thus gives, theoretically speaking, a greater "output" than it would

have from the flat and round surface, had the doline been filled up. Therefore the desire to fill up meadow-dolines should be superfluous, but nevertheless their number, in the studied time-interval, was halved (from 448 to 230) and their total surface decreased for 75 % (from 186,050 to 53,000 m^2). The mechanization in agriculture had a bigger impact on the diminishing number of meadow-dolines. With the transformation from manual labour to mechanised and more intensive agriculture, dolines became even more unpopular since they represented a relief obstacle to mechanised cultivation.

Fig. 1: Traditional meadow doline (photo by M. Gabrovec).

The construction of transport infrastructure in the area of Logatec had a strong impulse on relief changes in the past, particularly because of its geographic location. In the middle of the 19th century the so called "Southern railway line" was constructed through Logatec. Already at that time tracks were placed on filled up dolines that had been thereby lost forever and were even unable to be traced on the photograph from 1944. The burned waste of the railway however is the first known waste material that filled dolines around the Southern railway line. Furthermore it is not known how many dolines were filled

Fig. 2: The railway embankment of line Logatec – Idrija, closed after World War I (photo by M. Breg).

up with waste material from the railway embankment of the line Logatec – Idrija, close after World War I. Considering these historical facts there had probably been more dolines present in the studied area than were determined by the analysis of the aerial photograph from 1944.

Dolines have changed and disappeared also because of settlement-expansion as the area of Logatec has one of the most positive migration saldos in Slovenia. New neighbourhoods are being constructed increasing environmental pressures as more inhabitants cause more waste water, more waste dumps and consequently less dolines. Between 1944 and 2000, 154 dolines were fully or partly built-up representing 43 % of the total doline-surface (125,146 m^2). The number would increase greatly if the dolines that were destroyed by the commercial-industrial zone Logatec, which was built after the aerial photograph was taken in the year 2000, were included. Lost dolines that were covered with built surfaces during the last 50 years had been previously filled up with diverse materials – from excavation material to municipal and other types of waste.

FILLING-UP DOLINES WITH WASTE MATERIAL

On the study area of Logaško polje the degradation processes of dolines have been very intense during the last fifty years. From the aspect of nature protection and an environmental point of view it is important to identify the material used for filling up the dolines since these are areas of concentrated water through flow into the karst subterrain.

With the increase of municipal waste its percentage among the filling material rose. Over several decades the illegal waste dumps became a significant anthropogenic element in the karst landscape. Therefore not only their impact on karst aquifers and ecosystems has to be evaluated, but their influence on changes of surface geomorphology as well. With the used methodology and the acquired data it is difficult to define the number of waste-filled dolines since it is impossible to get access to the actual structure of the material. The clearest evidence is the abnormal texture identified on the aerial photographs (1944 and 2000) and typically characteristics for waste dumps. With this method, 74 dolines were marked

as a potential waste dump, but the greatest methodological weaknesses are several already overgrown and waste-filled dolines that were not marked as such.

Fig. 3: Waste dump (construction and demolition waste) in the meadow-doline (photo by M. Breg).

The increasing quantity of municipal waste was a suitable material for filling up dolines, especially during the 70's and 80's. A rather new phenomenon is the municipal waste of the recent decades. Regardless its size dumps contain different types of waste, also including domestic rubbish. Waste dumps in dolines were studied in detail by I. Šebenik (1994) in the scope of a research on illegal dumps in Slovenia. The author ascertains that areas with "suitable" locations for illegal dumps have several characteristics: they are accessible, less visible (physical depressions), covered by vegetation, remote, unfunctional and uninhabited. Two thirds of dolines filled with waste are located in the forest or are covered with a bushy-vegetation. Less than 15% of waste-dolines are in the form of meadows or abandoned pastures. Dumps in dolines are most commonly unspecific (these represent 84% of the waste), some are periodical or private. On both larger and smaller dumps mixed waste materials (including waste from households) prevail. A large part is in the form of dug material and tailings as a residue of different activities (e.g. house-construction), which are being transported to illegal dumps together with the rest of the waste. This kind of unusable material is very common in karst areas and in many cases represents the majority of waste materials. 75% of dumps are accessible through roads and only 10% of the waste is dumped beyond. Dolines are furthermore favourable dump locations due to their steep slopes that make depositing simple. In karst areas it is common to believe that dolines need to be filled up since they are only pointless and limiting holes (Šebenik, 1994).

With the handicraft and industrial workshops, new forms of hazardous waste products arrived that were dumped uncontrolled until the introduction of adequate legislation and the set up of regulated dumps. For the fill-up, different waste materials were used depending on their availability. With the growth of transport (railway), handicraft (blacksmith, charcoal-burning) and industrial activities (timber, cardboard-box and metal industry), hazardous waste products were produced. Several landfills that are already covered and overgrown contain heterogeneous and dangerous waste (sawdust, bark, industrial oils, galvanic sediment etc.) (Bricelj, 1988), that was deposited thirty years ago or even earlier.

With the population growth and production-activities, built-up surfaces and garbage quantity have increased. The municipality of Logatec produces yearly 4,000 tons of waste (SURS, 2005). Until the 90's the public collecting of municipal waste was gradually introduced in Slovene settlements that until then had to dump their increasing amount of waste somewhere nearby. Later it was taken over by public companies that continued to dispose the waste in dolines.

Regarding preliminary studies (Smrekar et al., 2005) active illegal waste dumps contain the highest percentage of construction waste (more than 70 %), while the percentage of municipal waste is decreasing. Considering these facts in combination with a growing migration and an increased interest for new or better lodging facilities on the Logaško polje the filling up of dolines with construction waste will most likely continue in the future.

INTEGRATED ISSUES FOR THE PROTECTION AND PRESERVATION OF DOLINES

Based on the presented example of the degradation of dolines on the Logaško polje and by considering the fact that it is a common problem in Slovenia (dumps and landfills in dolines in Slovenia, Šebenik 1994) it becomes obvious that dolines – a typical karst feature – are almost entirely ignored in the existing system of protection and planning of land-use, nature and environment. Dolines on the Logaško polje are the prevailing surface karst landforms and have in this form always been a strong element of the cultural landscape. The attitude of the population towards this landscape and the consciousness of the importance of its particularity have considerably changed with the diminishing role of agricultural activity (in society and space) and with the consequently diminished

dependency on natural factors. Secondary and tertiary activities, which are not exclusively based on local capital and natural resources, took the lead. The consequences provoked by non-agricultural activities in the karst landscape (construction, industry, transport etc.) are more unsustainable and less environmentally friendly than in the case of agricultural activities.

In the scope of the existing legislation it is necessary to define the possibilities for a long-term (sustainable) protection of dolines and to propose a new approach in spatial planning for geomorphologically unique doline-areas respectively. Considering the paradigm of sustainability the landscape and its landforms, as part of Earth's surface, would need to be treated as non-renewable natural resources – more precisely as a geomorphologic resource. Dolines are elements of the natural space which intervene with man's cultural space forming the unique karst landscape.

"A landform becomes a geomorphological resource only if it has social implications, that is, only if other parameters, external parameters, come into play to invest it with value (Panizza and Piacente, 1993). As long as a particular river, or a particular landscape are studied by and known only to scientists and researchers, it remains "private" knowledge and its potential as a resource do not materialize. However, if the scientist or the researcher publicizes it, making its cultural and environmental significance known to the general public and thereby giving it a social dimension, then the landform becomes a geomorphological resource in the eyes of society at large (Panizza, p. 22, 2003)." As a consequence it is necessary that dolines in the area of Slovene classical karst are considered as areas of geomorphological localities in the future planning of land use.

In comparison to subterrainean caves which are subject to the Cave Protection Act (Official Journal of the Republic of Slovenia (in further OJ RS), 2/2004), there is no similar act that would determine the protection and activity-management of doline-areas. The Environment Protection Act (OJ RS, 41/2004) foresees an environmental impact assessment prior to any activity affecting the environment. Before the start of such an activity it is necessary to conduct an environmental impact assessment, to obtain environmental protection consent from the ministry and to obtain an environmental protection approval (OJ RS, 41/2004, article 50-51). Thereby protected areas and natural values are being considered.

Considering the Nature Protection Act (OJ RS, article 37, 96/2004) the scientific evaluation measures are: exceptionality, typicalness, complexity, preservation, rareness and its importance for science and the ecosystem In case it isn't recognized as a natural value, a landforms can be incorporated in the framework of a protected environment. This guarantees a certain level of protection as any activity has to be in compliance with the protection arrangement of the relevant area. The Environment Protection Act defines further protected areas (national park, regional park and landscape park) and stricter protected areas (strict nature reserve, nature reserve, and natural monument).

In 1944 there were 569 dolines present in the studied area while until the 2000 only 51 (8.69 %) have been entirely preserved and 77 (13.5 %) have been almost (partly) preserved. In 46 years 441 dolines vanished resulting in the loss of almost 10 dolines per year. In accordance with the gained results from research-work and by considering sustainable and environmentally-friendly development dolines should be put under protection as a distinguishing karst feature and the level of endangerment for doline-areas to be determined. This would then represent the basis for future spatial-planning activities. As a unique feature dolines should be furthermore recognized by local inhabitants, as this is the only way to prevent their uncontrolled degradation.

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VISUALISATIONS OF THE HUMAN IMPACTS ON THE EARTH'S SURFACE

VIZUALIZACIJA KOT VPLIV ČLOVEKA NA ZEMELJSKO POVRŠJE

Tomaž PODOBNIKAR[1,2]

Abstract UDC 911.2:551.4

Tomaž Podobnikar: Visualisations of the Human Impacts on the Earth's Surface

The objective is to discuss the human impacts to the changing of the landscape surface. The study surface is mainly karstic part of Slovenia. The primary data sources are digital elevation models (DEMs) as continuous surface data, supported with aerial photographs, satellite images and older topographic maps. This study is supplemented with textual information about of historical surfaces. Geomorphologically high quality DEM of Slovenia with 12.5 m resolution uncovered many human impacts to the terrain surface, which could not be perceived before using any classical surveying techniques. Particularly on the karstic areas, changes of the surface as a consequence of highway constructions and developing of the stone quarries are well seen. Additionally is involved a database of natural (ridges, valleys, peaks, sinkholes) and antropogenic features (stone and gravel quarries, standing waters, different types of roads and railways) on the current terrain surface. Even more surface changes were found on the LIDAR-based DEM of 1 m resolution. Some human impacts to the surface changes from prehistory until today were analysed with many visual techniques and confirmed with objective numerical methods. The results show that is the human impact on the Earth's surface important factor that grows exponentially with time.

Key words: digital elevation model, GIS analysis, surface changes, visualisation.

Izvleček UDK 911.2:551.4

Tomaž Podobnikar: Vizualizacija kot vpliv človeka na zemeljsko površje

Namen prispevka je pretresti vplive človeka na spreminjanje značilnosti površja pokrajine. Za študijsko območje je bil izbran pretežno kraški del Slovenije. Podatki za analize so bili digitalni modeli reliefa (DMR), podprti z aero in satelitskimi posnetki ter s starejšimi topografskimi kartami. V pomoč so bili opisi zgodovinskih pokrajin. Na geomorfološko visokokakovostnem DMR Slovenije ločljivosti 12,5 m je bilo zaznati veliko človekovih vplivov na površje, kakršnih do sedaj s klasično zemljemersko tehniko nismo mogli določiti. Posebno na kraških območjih so opazni poteki avtocest in območja kamnolomov kot posledice spreminjanja površja. Izdelali smo zbirko podatkov naravnih (grebeni, doline, vrhovi, vrtače) in umetnih (kamnolomi, peskokopi, stoječe vode, različne kategorije cest in železnic) značilnosti površja. Še več sprememb površja smo našli na lidarskem DMR-ju ločljivosti 1 m. Analizirali smo izbrane človekove vplive na spremembe površja in pri tem uporabili več vizualnih tehnik, ki smo jih podprli z objektivnimi numeričnimi metodami. Rezultati analiz kažejo, da je vliv človeka na zemeljsko površje vedno večji ter in upoštevanja vreden.

Ključne besede: digitalni model reliefa, analize v GIS, sprememba površja, vizualizacija.

INTRODUCTION

The surface of the Earth is a dynamic formation. It is non-stop and step by step temporally changing in natural or anthropogenic way. Continental lithosphere plates are relatively slowly sliding beside each other, drifting apart or colliding. Earthquakes or volcano eruptions and additional phenomena like landslides or rockfalls acceler-

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ate the processes of landscape changes. Other, slower processes, like mechanical or chemical erosion, deposition, also influences to the surface shape. Soil and vegetation cover slow-down the surface change processes. During the last few decades, especially many human activities cause dramatic Earth's surface changes. Many of them are just different buildings – houses or bridges that are objects on the terrain and therefore more influence to the landscape changes than to the surface. More dramatic changes are highway constructions, stone sand and gravel quarries and clay pits, or rubbish dumps. The geomorphology or terrain surface has been therefore incorrigibly changed.

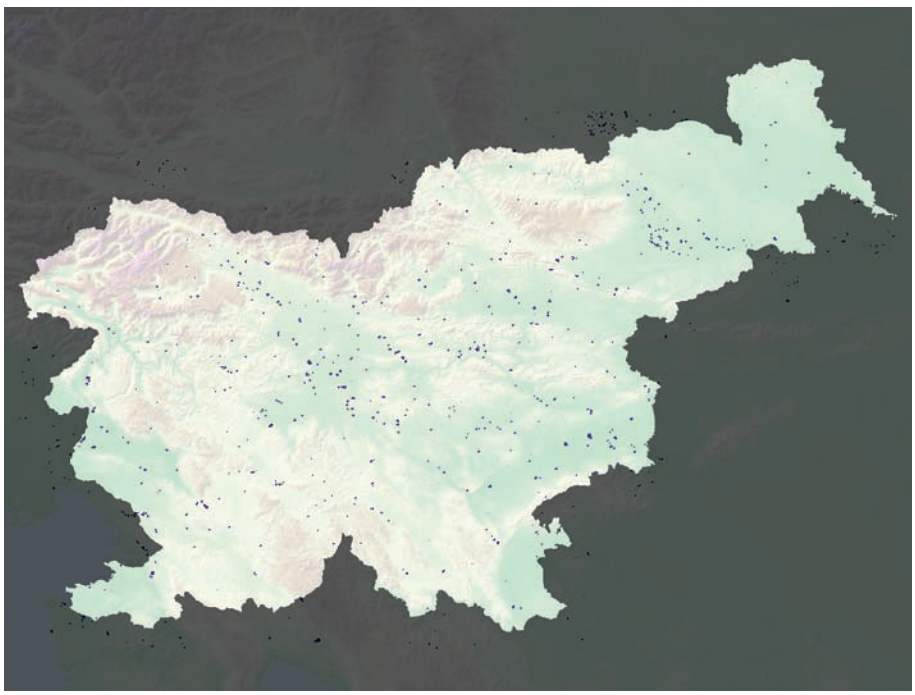

Fig. 1: Database of stone quarries in Slovenia, produced for DEM 12.5 modelling.

Human influences on the Earth's surface changes are remarkable for the more of last centuries. We can observe their activities since they have higher impact to the environmental and landscape changes than any other impacts like those from the animals. Anyway, coral polyps are slowly building coral reefs with their skeleton for millenniums; beavers have been constructing dams to regulate level of the water, etc. The early consequences of landscape changes due to human needs like levelling the fields, building terraces, constructing the walls, etc. are easily perceivable. We can still easily find walls of the prehistoric hillforts (cf. during the Bronze Age, Fig. 6). On the surface is also perceivable the old pre Roman course of river Ljubljanica (cf. Fig. 8a). Romans shifted the river stream to establish a stone quarry in Podpeč for building up and supporting their city Emona. For the most of surface changes done until the 20 century we can consider that people did them with high respecting of the environment. In fact they could not drastically change the Earth's surface because the work was manual or using low power machines. But nevertheless the effect of their changes of the landscape has been naturally or on the other way blurred since that time by so called renaturalisation process.

Newer human's impacts to surface are more and more brutal. Landscape is wounded with newer and bigger structures and other irreversible interventions to the surface. On Slovenian landscape is the most remarkable highways construction. That network will be build up in few years in a total length of 518 km (DARS, 2006). This will change at least 25 km2 of surface. That means converted to square shape around 5 x 5 km, what is comparable with the area of town Ljubljana. For 1 km of highway around 18,000 m^3 of material is needed acquired on the area of highways and form stone quarries (DARS, 2006), with a total amount of around 0.01 km^3 (or more than 200 x 200 x 200 m). During the modelling of digital elevation model (DEM) of Slovenia we registered 713 stone quarries to our database (included 295 gravel quarries and 127 abandoned ones) that cover at least 15 km^2 of Slovenia (Fig. 1). If we consider almost 1.4 million of buildings that exist in Slovenia, with approximate changed surface of 200 m^2, it sums up to 280 km^2. We should add other roads, rubbish dumps and tailings or other material deposits, too. Applying very rough estimation, currently at least 2% of Slovenia's surface is much changed by humans (cf. Fig. 10), but the impact area is much larger (e.g. considering impact areas around buildings, ski resorts).

Many other projects that ineligibly change the surface – especially on the karst area are easily perceived building of large buildings, ski resources, industrial trade-zones, power plants, mining activities, etc. Some of such projects are described: The location of the European Karst Museum (EKM, 2006) is planned on naturally undamaged area, in our opinion, more acceptable locations

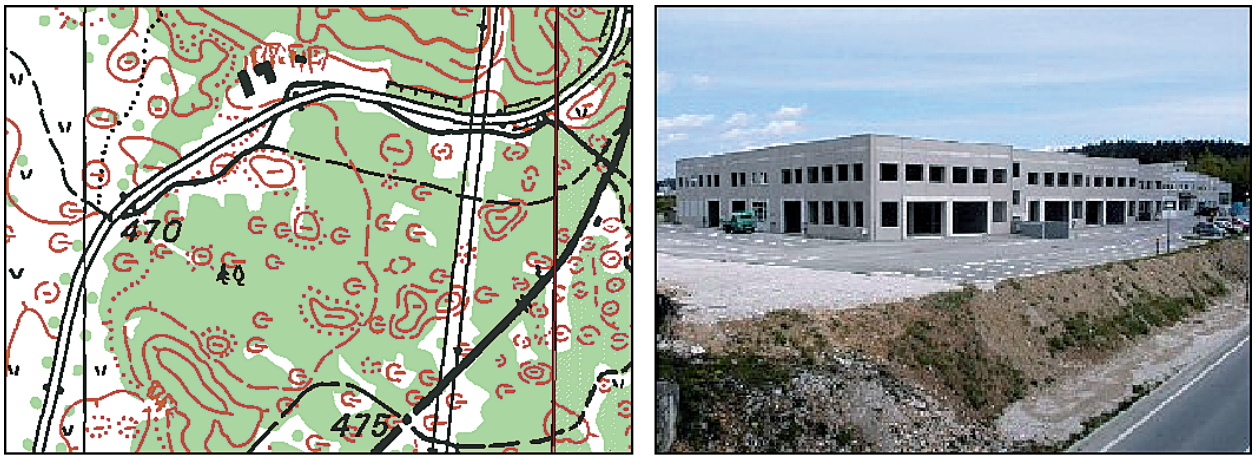

Fig. 2: a: Large area of primary rough natural karst surface (DTK25, © Surveying and Mapping Authority of RS) was b: completely flattened for industrial-trade zone Logatec.

should be considered such as degraded areas around – stone quarries or low quality urban areas. Most of ski resources are "improved" by flattening the ground and by building of the accommodation capacities (e.g. Kanin and Boevec). Planed buildings in industrial-trade zones like Sežana, Logatec or Cerknica-Podskrajnik changes larger areas completely (Fig. 2). The projects like wind power plants (i.e. Volovja reber) should be also planned with inclusion of more professional arguments than with political and capital power (Podobnikar and Zakšek, 2005) as at least many new roads should be built on vulnerable karst area. The other remarkable changes are depressions formed as consequences of mining – i.e. the lakes on the abandoned coal mine near Velenje are still increasing (Oštir, 2000; Komac, 2006). Morphological changes in this last case are conditionally acceptable for aesthetical and even ecological view, as they have nearly natural appearance comparing to other landscape patterns.

The changing of the Earth's surface and its visual impact is related with environmental aesthetics. It is temporally changes with newer reveals and even with the fashion. Aesthetics is the field of philosophy that studies the ways in which humans experience the world through their senses, or shortly, it means visual pleasing. Environmental aesthetics extends beyond the narrow confines of the art world to the aesthetic appreciation of human-influenced as well as natural environments (Carlson, 2002). Aesthetics is connected with scenic landscapes where most people reportedly enjoy most. A Visual Resource Management (VRM) is a system which involves inventorying scenic values and establishing management objectives (VRM, 2003). The values evaluate proposed activities and determine whether they conform to the management objectives. Beautification process of making aesthetical visual improvements is typical for urban areas but can be applied for the natural environment. Generally the environmental aesthetics is decreasing regarding mentioned criterion that is obvious applying visual analyses in this paper.

The motivation for this research was the inflation of anthropogenic changes that was considered during the DEM 12.5 of Slovenia production (Podobnikar, 2005b). For the integration of DEM from various data sources, special methods were developed for recent anthropogenic surface changes due to the problem that most of the human activities are not registered in 3D databases. With different approaches were integrated roads, highways, railways, buildings, stone quarries (surface mining), dams, and other changes, especially rubbish dumps. After those procedures the DEM didn't appear anymore geomorphologically natural. For the first time we could observe impacts of different kinds of the recent buildings, especially on the detailed map of Slovenia (Podobnikar, 2005a) and on the other developed visualisations of surface (Podobnikar, 2007). Such DEM can not be used for understanding geological details or natural forms of the Earth's surface. Additional motivations of this research were interesting topographic information from the older topographic maps that show environment with more natural surface characteristics than newer data sets. This data can be used also for understanding natural landscape and geological formations or for palaeo-DEM modelling (Podobnikar and Šinkovec, 2004). The DEMs and maps are important sources for monitoring the surface changes, but they are rather neglected in comparing with generally more attractive and mastered satellite images.

DATA SOURCES FOR VISUAL ANALYSIS

Our study area was entire Slovenia with focus on the karst areas. The main data sources were DEMs. The other data sources that supported the study were topographic maps, especially historical maps, aerial photographs, and satellite images of different age. All of the data were digitised and georeferenced to the common coordinate reference of the Slovenian national cartographic system, bases on Gauss-Krüger coordinates. Overall high and known (evaluated) quality was the most important property for the data sources used in the study. Modelling the spatial data, analyses and visualisations were produced with tools based on geographical information systems (GIS).

Aerial photographs and satellite images are common and standard data sources for observation the changes of the Earth's surface. We have used some digital orthophotos from different periods from the Surveying and Mapping Authority of Republic Slovenia and high resolution satellite images available in Google Earth (Google, 2006).

The historical maps are the most important sources for the various spatial analyses of the historical landscapes, urban development, influences of the economy development, toponymes changes, land use, etc. (Podobnikar and Kokalj, 2007). Some information there is more implicitly noted, more difficult understandable and therefore less objective than from historical texts. Georeferencing of digitised versions of those maps is also not as trivial as for nowadays maps or satellite images, especially because of the unknown coordinate systems and unpredictable distortions due to simple techniques of measurements and sometimes mapping without any measurement. We used some older and new maps from Surveying and Mapping Authority of Republic Slovenia and historical maps that are up to 250 years old (the maps are listed below the figures).

With radar differential interferometry techniques (ESA, 2006; Oštir, 2000) we can track even small changes of the surface heights continuously and precisely over a particular area. A differential interferometry is useful for perception and measuring the changes of the surface consequences of earthquakes or some human's activities. With the radar interferometry can be produced numerically low to medium quality but geomorphically overall homogeneous DEM.

Using the aerial laser scanning equipment, a high quality LIDAR-DEM of 1 m resolution was produced for the area that transact Kras region in direction east-west, with dimensions of 2 by 20 km. Primary usage of this data layer was vegetation density research for which the laser scanning methods are suitable and promising (Kobler, 2006).

DEMs are amongst the most applicable layers in GIS applications (Burrough and McDonnell, 1998). Because they are our main data source in this paper, we are going to describe it in higher detail. In general, DEM is considered as a "raster dataset" (grid). Each square cell of the grid contains the elevation value (height) for the centroid of the cell. The finite set of cell heights can be interpreted in two ways. With the first approach, each cell can represent a discrete area, hence the entire cell is assumed to be of the same value, and changes occur only at the border of the cells. With the second approach, the surface area between the cell centres is assumed to have some intermediate values. The second approach is closer to the DTM (digital terrain model) definition. DTM is considered a continuous, usually smoothed surface which includes, apart from the values of height (DEMs), other elements that describe the topographic surface, such as slope, aspect, curvature, gradient, skeleton (sinks /karst dolinas/, valleys /thalwegs/, saddles, ridges /crests/, and peaks), and others (Podobnikar, 2005b).

DEM is just a model of the Earth's surface. Its specification as a model includes: natural and artificial standing water surfaces, glacier surfaces, artificial terraces and dams, stone, sand and gravel quarries, surface mining processes, rubbish dumps and other deposits, mound and dikes or removal of earth for roads, railways, parking places, airports, levelling of original landscapes for easier moving or making fields, ameliorations of the river courses, and many other artificial changes of our surface (Podobnikar, 2005b). Buildings, for example houses or bridges are not considered to be part of DEM.

Historically, digital elevation models have been introduced in mid-fifties in the United States. The concepts of DEM production are connected with development of computer science, which enabled effective analytical data processing. In Slovenia the first researches for the DEM production started in the late sixties. In 1973 they started with production of DEM 100 for the whole of Slovenia. In 1975 DEM 500 for entire Slovenia had been produced (sources were topographical maps in scale 1:25,000, 1:50,000 and 1:100,000). The DEM 100 was finished in 1984 (sources were topographic maps in scale 1:5000 and 1:25,000). In 2000 was produced InSAR DEM 25 that employed radar satellite images and some other data, and in 2001 a DEM 25 photogrammetrically from aerial photographs (Podobnikar, 2003). In 2005 a DEM 12.5 from different data sources was produced, which has roots in DEM 20 for 1/8 of Slovenia that was produced in 2001 (Podobnikar, 2005a).

The old elevation models are unfortunately too coarse or of too low numerical and geomorphic quality for observing the human influences to the surface. In spite of the fact that older data are of lower quality, temporally

different DEMs will help in the future to observe surface changes. At the moment, older maps of different scales and aerial photographs can help to digitise and describe some past surface changes, and therefore at least virtually preserve natural heritage to our descendant. In the future, environmental changes should be precisely observed and mapped in 3D. The series of surface changes in Slovenia should be therefore used for producing the DEMs that describe its changes over the time. The first DEMs that have been useful for observing the human impact (without the support of aerial photographs or satellite images) was DEM 25 with its first parts produced in 1995. The first DEM that was geomorphically continuously treated for all of Slovenia was DEM 12.5. On it we can clearly notice plenty of natural and anthropogenic changes. This data layer is a base for our mostly visual research of the human impacts to the terrain surface.

VISUAL ANALYSIS

Spatial analyses are among the most important capabilities of the geographical information systems. We distinguish between qualitative and quantitative analyses. Possible solutions of qualitative analyses can be explained with visualisations. This study is stressed on descriptive analyses that can answer to the basic questions on the spatial patterns. Unfortunately the quantitative spatial analyses tend to subjectivity in evaluation. With visual analyses of the significant parts Earth's surface, and with space-time series visualisation, we interpreted and understood some impacts for changes of the surface.

The course of Ljubljanica River had been much influenced by human demands at least since Roman period (Podobnikar and Šinkovec, 2004). On the Fig. 3 are visualised some previous river courses regarding some present-day data sources. The example *a* describes a plan of Florjančič from 1744 where Gruber canal hadn't existed yet. On the picture *b* Austrian 1st Military Survey map that was produced between 1763 and 1787 is presented. The Gruber canal had already been mapped, but the lower course of Ljubljanica river was still much different from the present, which is presented as blue vector line over the map. Despite this data are only two-dimensional, we can easily imagine that river courses influence to the surface shape (e.g. Bec and Podobnikar, 2006). Surface changes can be examined by DEM 12.5 more detailed (c). We visualized them applying bipolar differentiation method with 3 m interval (Wood, 1996) in combination of hill shading (Podobnikar, 2005). Present Ljubljanica river and Gruber canal courses can be clearly observed in addition to railways, roads and quarries, etc. We can easily find correlations between the courses on the old maps (a and b) and patterns on the DEM (*c)*. Regarding the other patterns on the DEM we can suspect positions of even much older (palaeo) river courses.

Higher precision LIDAR-DEMs will be in the near future applicable for many different fine patterns recognition. LIDAR-DEM with resolution of 1 m has so many details, that some patterns which seemed to be gross errors later were proved as consequences of the World War 1 (Fig. 4). Such data of the surface could help in the near future to reconstruct some missing facts of our history.

In general, to observe recent crucial surface changes are not needed that high precision data as it is a LIDAR-DEM. Some changes of the surface were observed on different versions of up to ten years old DEM 25 and on the newer DEM 12.5. These examples are continuous operations of the around gravel quarry Stanežiče near to Ljubljana and at stone quarry Stahovica near to Kamnik.

The DEM 12.5 on the Fig. 5 is visualised by hill shading, enhanced ridges and by hypsometry using different colours. Both, hill shading and enhancing the edges were modelled in different scales and with different parameters to emphasize multi-scale effect (Podobnikar, 2005a). On this cut out of the map, especially ridges are more visible perceivable with increasing brightness regarding natural aspect of the landform curvatures. For example, the result is similar with worn jeans on its edges or edges of table that became brighter. On the map can be noticed that most of the area is karstic with many dolinas or sinkholes. Besides of dolinas, a considering amount of human impact can be interpreted, too – especially very recent highways and a stone quarry. Less visible are older roads and railways.

On the Fig. 6 DEM 12.5 *(a)* and LIDAR-DEM 1 *(b)* are interpreted with direct comparison of both data of different resolution. On the picture a we can observe rough traces of coarser features like rings (walls) and lines (roads, railways), but all of the patterns are rather "blur". On the picture *b* many more features and patterns can be observed. We can also do a visual quality control of the DEM 12.5 regarding more precise LIDAR-DEM 1. We can see for example that some sinkholes on the lower left corner in the picture a are missing regarding the picture b. The errors are a result of more subjective manual measurements and mapping (generalisation) in the past, as this DEM was produced with fusion of about 30 data sources where the oldest are more than 50 years old. Higher quality LIDAR-

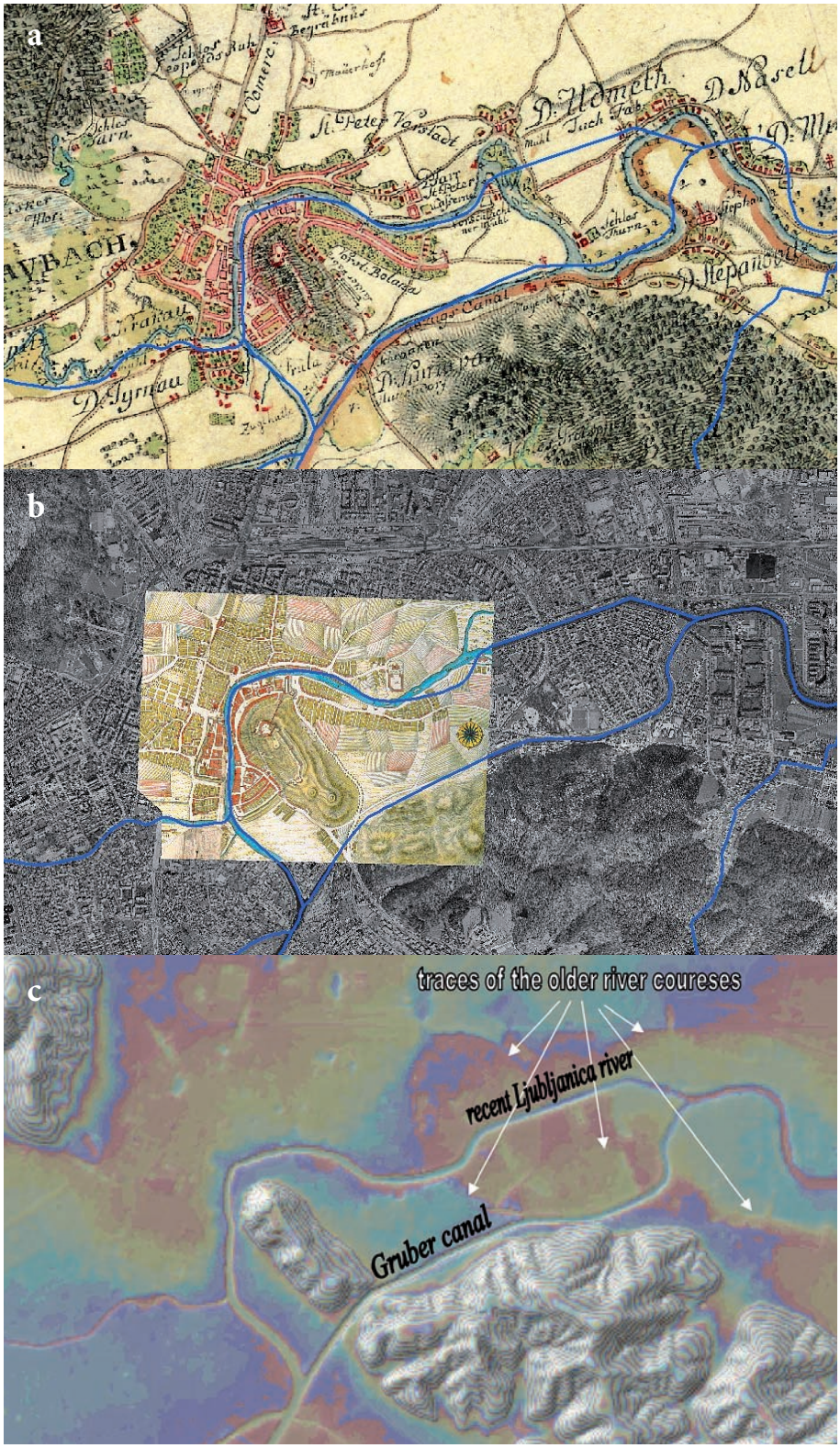

Fig. 3: Changes of the river courses: a: Florjančič plan without Gruber canal (DOP5, 2002 © Surveying and Mapping Authority of RS), b: Austrian 1st Military Survey map with the canal. Overlaid blue vector lines indicate current streams of the rivers. On the c: older river courses are recognisable (DEM 12.5, 2005 © Surveying and Mapping Authority of RS).

DEM 1 can be resampled to coarser resolution of 12.5 m and used for improvement of some remarkable wrongly interpreted areas on the DEM 12.5 during its processing (Podobnikar, 2005b).

On the Fig. 7 can be seen that rubbish dumps are easily perceivable on a DEM 12.5. They were compared with satellite images acquired from Google Earth *(a)*. With terrestrial laser scanners we can measure smaller structures in a high precision and resolution with much lower expense than using airborne laser scanned data. The main advantages of LIDAR regarding classical surveying measurements are higher speed of surveying and almost continuous high precision data. The picture b shows the velocity of filling some parts (fields) of Ljubljana's dump. Filling of this dump with rubbish is so fast, that monitoring can not gain upon up-to-dated DEM with appropriate accuracy, even for DEM of Slovenia with resolution of 12.5 m (DEM 12.5). On the picture a are described positions of the five fields and three phases and the status of the filling up process on the DEM (left) and Google Earth (right). Comparing a with b we can see that data on the DEM 12.5 are probably from the first part of 2005, but on the Google Earth from the beginning of 2004 or before.

In parallel with DEM 12.5 modelling, layers of different structure lines of the Earth's surface were produced: ridges, valleys, sinkholes and peaks, layer of stone and gravel quarries, layer of all standing waters

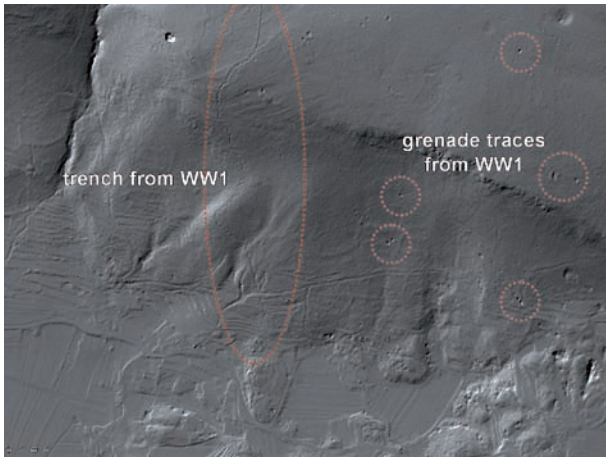

Fig. 4: Trench and grenade traces (LIDAR-DEM, Kobler, 2006).

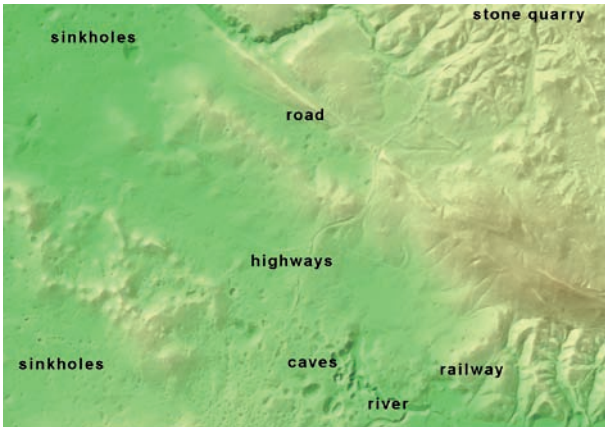

Fig. 5: Ancient and recent surface patterns (DEM 12.5, 2005 © Surveying and Mapping Authority of RS; map by Podobnikar, 2005a).

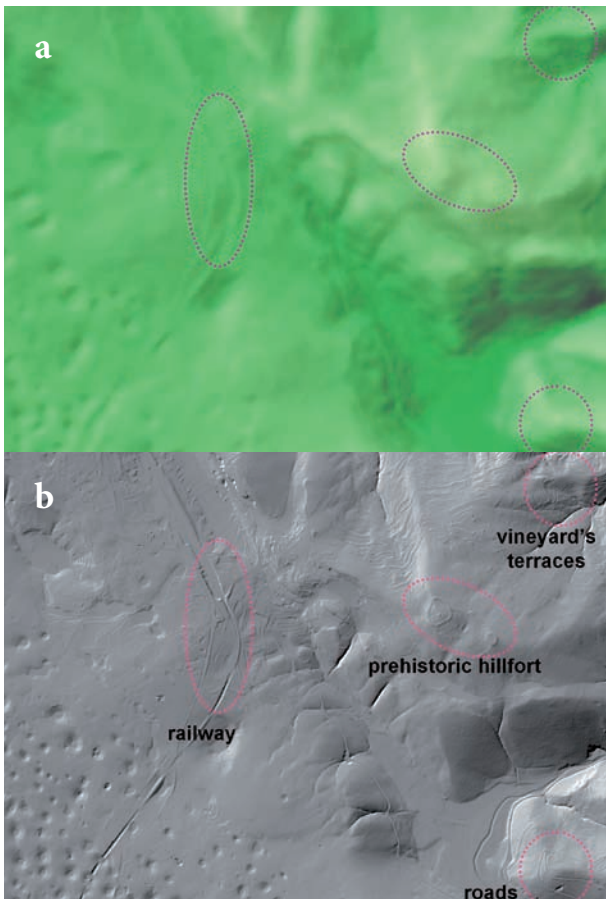

Fig. 6: Comparison of DEM 12.5 (a) and LIDAR-DEM 1 (b) on the same selected area. On the picture a we can observe many details, but there are still many uncertainties comparing b.

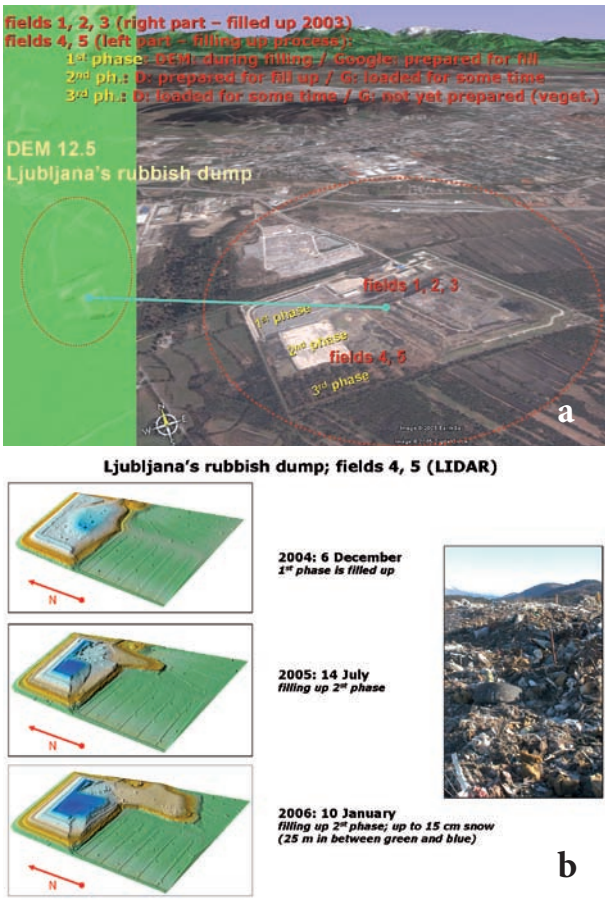

Fig. 7: a: Ljubljana's rubbish dump on a DEM 12.5 in comparison with the high resolution satellite image (Google Earth). b: Phases of successive formation of the artificial hill that is rising, using terrestrial laser scanner (DFG SNAGA, 2006).

including artificial ones, and layer of different types of roads and railways. These particular data based mostly on the human impacts to the surface and can be used for monitoring of major Earth's surface changes. Quality, especially height accuracy of all these data was also evaluated for every grid cell of 12.5 m (Podobnikar, 2005b).

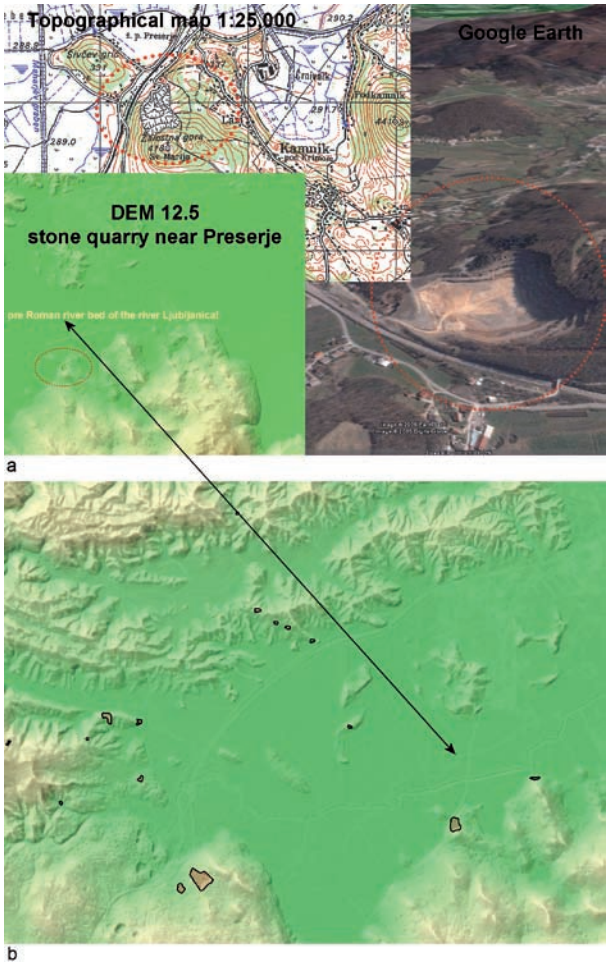

Fig. 8: In the picture a, stone quarry presented with DEM 12.5, symbol on topographical map in scale 1:25,000 (DTK25, © Surveying and Mapping Authority of RS), and as pattern on a satellite image (Google Earth). On the DEM, a pre Roman course of Ljubljanica river is noticeable. The stone and gravel quarries database around Vrhnika are presented in the b.

Stone and gravel quarries are clearly perceivable on the F*ig. 8a:* A DEM 12.5 is used for that presentation with its differences of heights, insertion of topographical map with their symbols and satellite image of Google Earth with recognisable patterns of the landscape were used. A detailed part of database is shown in the picture *b* (cf. Fig. 1). This database might be compared with the official database. Comparison with the Corine Land Cover shows, that the latter doesn't contain most of the smaller quarries and their shape is rough.

Fig. 9 compares two groups of data sets. In the picture a all buildings, main roads and quarries are located. We can see that within some regions, most of area is settled or impacted by humans. On the picture *b,* the database of sinkholes distribution (produced for the

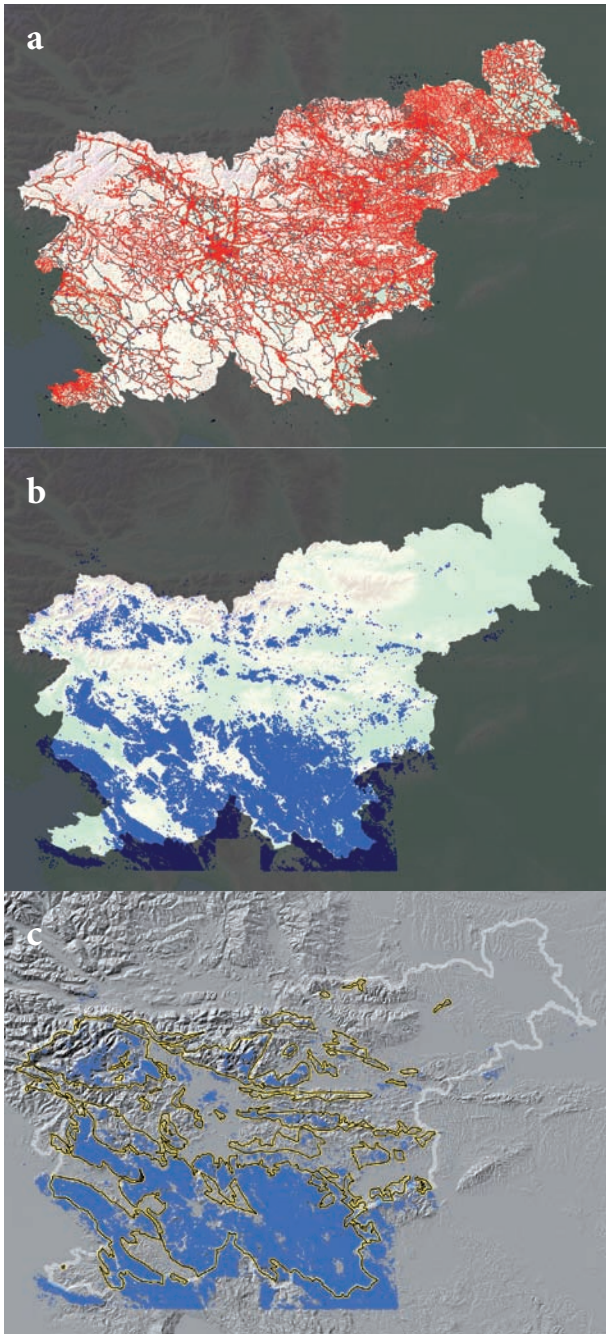

Fig. 9: a: Buildings, main roads (both © Surveying and Mapping Authority of RS), quarries as most of recent surface changes comparing with b: distribution of sinkholes and c: sinkholes comparing with karst areas in Slovenia (Čar, 1978).

DEM 12.5 modelling) shows that large part of Slovenia is potentially karst. The most interesting is comparing two visualisations. We can perceive complementarity of both pictures: areas that are built-up *(a)* are not much karstic *(b)*. And opposite, karstic areas are not much built-up.

DISCUSSION AND CONCLUSIONS

Current human's changes of the Earth's surface are just some of the many other aspects that changes beings on the Earth. We stressed this study on visualisations of the recent human impacts. We found out that they are much more visible than the changes, older than few decades ago. Most of the large surface changes are (fortunately?) invisible from the cities, roads, or paths. Numerical simulations refine and different visualisation strategies help to weigh up his decisions.

We found out that most of the human impacts are more visible on the Earth's surface than we could imagine before. Obviously the Slovenian environmental legislation can not manage some real interventions – at least considering stone quarries as important human's impacts (713 in our database). We noticed that the official database of non metal mineral row materials consists 685 locations. In ARSO (2002) is also noticed that those locations don't cause major environmental loading. Obviously they were not considered some significant environmental indicators in this research. With our analyses we found out even prehistoric walls, some later river regulations, ancient and recent land terraces for vineyards, bomb traces from the World War 1 are easily recognisable on the analysed data. Recognizing those old patterns is also of advantage, because that information could be useful for better understanding of our history, and the power of the current surface changes. With comparing of the outputs we have observed (but we haven't evaluated numerically) that are just one year old changes of surface greater than all of the changes until 19th century. The most recognisable current changes of the Slovenian surface are enlargements of quarries, new rubbish dumps, large buildings, and highways construction – especially on the specific karst areas. Karst area is vulnerable with its unique and uncovered surface, and subsurface (caves), karst water systems, water supply (poor filtration of water that penetrating), possible deforestation, etc.

Some of the human's impacts on the Earth's surface changes were visualised and numerically interpreted using georeferenced spatial data in Slovenia. We have demonstrated those changes by means of using high quality data, efficient tools and creative visualisation approaches. The study referred to DEM 12.5 and on its derivatives as quarries and sinkholes data sets. The secondary data sources were other DEMs, historical maps, and aerial photographs and satellite images. The DEM 12.5 was visualised by simple hill shading, hypsometry or more complex bipolar differentiation, enhancing of the edges, with multiscale presentations, etc. Visual mutual presentations of more data layers were more effective with comparing the same cut outs as "picture by picture" or transparently overlaid picture over the other picture. Preparing high quality data was necessary for the satisfactory results.

We found out that information about the past is important for understanding the development of the surface changes. For that the historical maps are important data. The recent satellite images and especially DEMs are important sources for tracking the human's changes through the time. For the experienced operator the visual methods - as they offer more semantic information - are at least at the first stages of research more practical than automated numerical methods. The visual methods could be source for the further automated methods for recognising possible artificial geomorphological artefacts. The presented visual methods already demonstrate some tools for detection of geomorphological features.

As was established also in Podobnikar and Kokalj (2007), the historical data are helpful for better understanding development of the human's impacts to environment. Unfortunately they are not much useful for systematic survey of the changes. The problem lies in thematic, positional and temporal homogeneity/accuracy of the data and also on the selection of the mapped themes. Particular changes that reflect significant changes of the environment (e.g. Gruber canal) were tracked through all data sources. On a high quality DEMs (DEM of Slovenia, LIDAR-based DEM) the traces of the many anthropogenic and natural changes (e.g. around Gruber canal) can be observed using only one data layer. Additionally the analyses should consider that overall quality of data sources generally increases by time.

Our society should more careful treat further interventions that can visually preserve the environment. Many possible solutions can lead to more sustainable development. Here are some possible examples. Transportation is a big problem, where especially the highways construction destroys a natural surface. Currently, only around 5% of transport in Slovenia is carried by trains. For example, to the intelligent system could be connected more vehicles as automatically controlled convoys on the existent roads (automatic driving on short distances in between vehicles; IMTS, 2006) and on that way the impact could be lower. To the less impacts to the environment is connected a Happy Planet Index (HPI). It is intended to challenge well-known existing indices of a state's success, such as Gross Domestic Product and Human Development Index (NEF, 2006). It bases on the amount of the Earth's resources they use, and the length and happiness of people's lives. The HPI shows that people can live long, happy lives without using more than their fair share of the Earth's resources. On that way was

for our use demonstrated that rapidly and much unpredictable changes of the Earth's surface are not source of the future happy environment. Some conservatism in the progress with much wisdom can lead to better live. Are we going to preserve unique and beautiful landmarks of Slovenia like they are presented by Burger (2006)?

ACKNOWLEDGMENT

All of the presented digital spatial data were not produced by the author. Some elevation models, aerial and terrestrial LIDAR measurements, orthophotos, historical and contemporary maps were kindly provided by following persons and organisations: Andrej Kobler – Slovenian Forestry Institute, Domen Smole – DFG Consulting, Irena Šinkovec – Municipal Museum of Ljubljana, and Surveying and Mapping Authority of RS, Franjo Drole – Karst research instate, ZRC SAZU

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COBISS: 1.01

UGOTAVLJANJE DINAMIKE PRETAKANJA PADAVIN SKOZI VADOZNO CONO KRASA NA OSNOVI MERITEV PRETOKA

RAINWATER PERCOLATION DYNAMICS ASSESSMENT THROUGH THE VADOSE KARST ZONE ON THE BASIS OF DISCHARGE MEASUREMENTS

Janja KOGOVŠEK[1]

Izvleček UDK 556.3(497.4)

Janja Kogovšek: Ugotavljanje dinamike pretakanja padavin skozi vadozno cono krasa na osnovi meritev pretoka

Raziskave na osnovi občasnih, kasneje pa zveznih meritev padavin na površju in pretokov značilnih curkov v Postojnski jami, 100 m pod površjem, so podale dinamiko pretakanja v času hidrološkega leta. Pokazale so na več mesecev trajajoča poletna obdobja, ko se vse padavine, tudi tiste izdatnejše, shranjujejo v vadozno coni. Po daljšem sušnem obdobju se prve reakcije pretokov curkov na padavine močno razlikujejo, medtem ko v namočenem obdobju nismo zabeležili večjih razlik. Iztekanje vode v upadajočih delih vodnih valov se med curki bistveno razlikuje in med njimi smo prepoznali tipe curkov, ki napajajo kraške vodonosnike tudi v času nizkih vodostajev oz. nizkih pretokov kraških izvirov.

Ključne besede: kraška hidrologija, vadozna cona, vodni val, Postojnska jama, Slovenija.

Abstract UDC 556.3(497.4)

Janja Kogovšek: Rainwater percolation dynamics assessment through the vadose karst zone on the basis of discharge measurements

Researches based on seasonal and later continuous measurements of precipitation on the surface and discharges of typical trickles in Postojnska Jama, 100 m below the surface, showed the dynamics of percolation in a period of a hydrological year. They registered summer periods lasting several months when all the rainfall, even more abundant, is stored in a vadose zone. After a longer dry period the first discharge reactions of trickles to rainfall strongly differ while there is no substantial difference in a wet period. The water outflow in decreasing parts of water pulses essentially differs among various trickles and we recognised the types of trickles feeding karst aquifers even during low water level or low discahrges of karst springs.

Key words: karst hydrology, vadose zone, water pulse, Postojnska jama, Slovenia.

UVOD

Vir kraške vode so padavine, ki vstopajo skozi prst v vadozno cono, od koder po daljšem ali krajšem zadrževanju odtekajo in napajajo kraške vodonosnike. To pretakanje so preučevali z različnimi pristopi in metodologijami že številni raziskovalci: Bakalowicz et al. 1974, Williams (1983), White (1988), Jeannin & Grasso 1995, Perrin & Jeannin & Zwahlen 2003 in številni drugi. Anna F. Tooth in Ian J. Fairchild (2003) sta preučevala preniklo vodo v Crag cave na Irskem s 40 m debelo vadozno cono v dveh krajših obdobjih, avgusta 1997 in januarja 1998 in na osnovi dnevnih hidrokemijskih meritev ter izdelala hidrogeokemijske modele. V zadnjih 30 letih so potekale tudi na slovenskem krasu raziskave prenikanja skozi vadozno cono (Kogovšek & Habič 1981; Kogovšek 1982; Čenčur Curk 2002).

Naše raziskave s pogostimi ročnimi meritvami pretoka (1 do 2-krat dnevno) curkov in kapljanj v Kristalnem rovu ter bližnjih curkov v Glavnem rovu Postojnske jame smo začeli spomladi 2002 in so trajale do jeseni 2003 (Sl. 1). Meritve v hidrološkem letu 2002/03 so pokazale letni potek pretokov in različne tipe curkov. Izstopajo daljša obdobja, ko se infiltrirane padavine niso neposredno odrazile v povečanju pretokov in so se torej porabile za zapolnjevanje zaledij curkov, in »namočena« obdobja, ko

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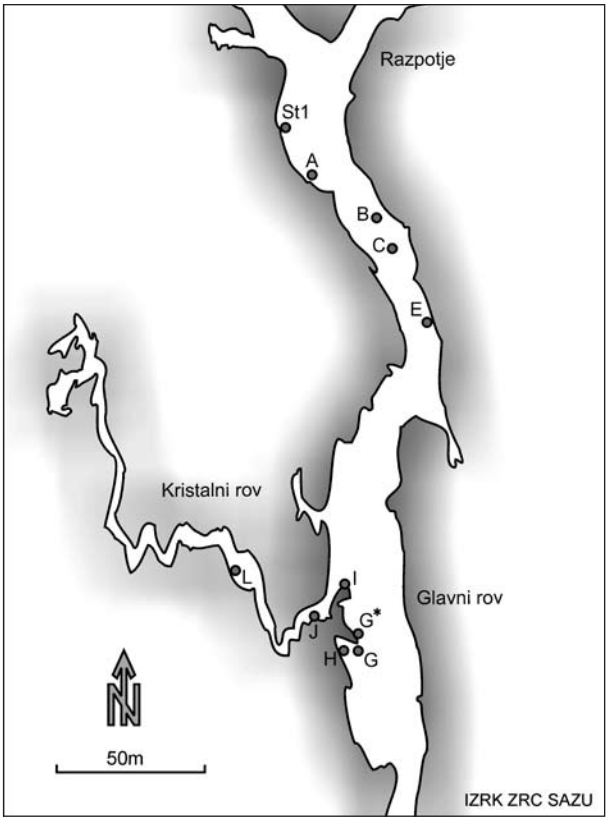


Sl. 1: Položaj opazovanih curkov v Postojnski jami.
Fig. 1: Location of observed trickles in Postojnska jama.

so pretoki curkov hitro in izrazito reagirali na padavine. Pri oblikovanju vodnih valov curkov po padavinah ob različnih hidroloških razmerah smo ugotavljali, da prihaja med njimi do razlik, vendar pa so bile meritve 2-krat dnevno nezadostne za podrobnejšo oceno. Zato smo za nadaljnje raziskave izbrali tri značilne curke: curek I s pretokom do več 1000 ml/min, manjši curek J s pretokom do 130 ml/min ter kapljanje L s pretokom do 6 ml/min (Sl. 1). Z zveznimi meritvami pretoka smo začeli leta 2003 in so trajale celo hidrološko leto 2003/04 do jeseni 2004.

Vloga vodozne cone pri pretakanju padavin do kraških izvirov so pokazala tudi sočasna sledenja z umetnimi sledili neposredno s kraškega površja (Kogovšek & Petrič 2006).

METODE DELA

Za podatke o dnevni količini padavin sem v letu 2002 in delno v letu 2003 uporabila meritve Agencije republike Slovenije za okolje za padavinsko postajo Postojna Zalog. Od junija 2003 pa smo začeli z lastnimi meritvami padavin na površju nad poligonom raziskav v Postojnski jami, na robu ograjenega dela vojašnice Slovenske vojske, saj smo ugotavljali, da občasno lahko prihaja do večjih razlik v razporeditvi, pa tudi količini padavin na krajše razdalje. Meritve so potekale z dežemerom z dataloggerjem HOBO Event Logger, firme ONSET (Sl.2), ki zabeleži vsakih 0,2 mm padavin. Tako sem dobila podrobno razporeditev količine padavin v času.

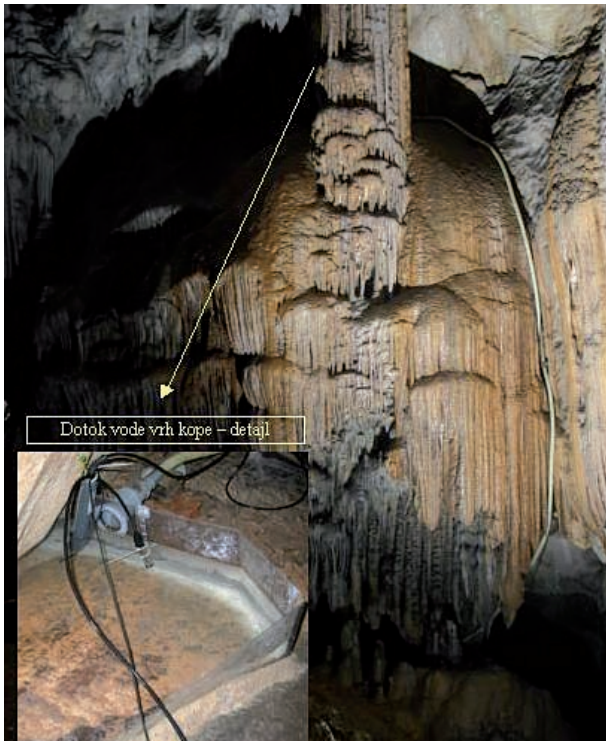
Prve meritve pretokov v hidrološkem letu 2002/2003 so potekale na točkah I, J, G, G*, H in L ročno enkrat do dvakrat dnevno, ko smo jih merili ročno s štoparico in ustreznim merilnim valjem, medtem ko so na točkah St1, A, C, E in B potekale le do konca leta 2002. Že v naslednjem hidrološkem letu 2003/2004 pa smo na treh izbranih točkah I, J in L začeli z zveznimi meritvami oz. z meritvami v časovnem intervalu 15 minut.

Na točki I smo po podrobnem ogledu curka po izdatnejših padavinah ugotovili, da priteka voda na vrhu približno 6 m visoke sigove kope. Glede na predhodne občasne meritve sem sklepala, da pretok lahko dosega do nekaj l/min. Zato smo na dotoku vode vrh kope naredili manjšo zajezitev z vgrajenim prelivom. Ob njem smo pritrdili sondo za merjenje nivoja (Sl. 3). Uporabili smo Thermos data TL2 firme ENEA, ki je beležil meritve nivoja vsakih 20 minut oz. vsako uro. Na osnovi ročnih meritev pretoka in zveznih meritev nivoja s sondo sem izračunala funkcijsko odvisnost pretoka od nivoja (konsumpcijsko krivuljo) ter meritve preračunala v pretoke, ki so podali hidrogram curka I.

Meritve pretoka stalnega curka J s pretokom le do nekako 130 ml/min (meritve od leta 2002 dalje) sem morala zasnovati drugače. Vodo s curka sem speljala v posodo z majhnim iztokom (luknjico), v kateri smo s sondo merili višino vode (H) vsakih 15 minut (Sl. 4). Z občasnimi meritvami pretoka z merilnim valjem in štoparico ob najrazličnejših pretokih sem izdelala umer-

Sl. 2: Meritve padavin so potekale z dežemerom z dataloggerjem HOBO Event Logger.

Fig. 2: Measurements of pricipitation with HOBO Event Logger.



Sl. 3: Merjenje pretoka curka I na vhodu v Kristalni rov.

Fig. 3: Discharge measurements of trickle I at the entrance to Kristalni rov.

Sl. 4: Merjenje pretoka curka J v Kristalnem rovu.

Fig. 4: Discharge measurements of trickle J in Kristalni rov.

Sl. 5: Merjenje pretoka na točki L v Kristalnem rovu.

Fig. 5: Discharge measurements of dripping point L in Kristalni rov.

itveno krivuljo. Preračun izmerjenih vrednosti nivoja v pretok nam je podal hidrogram curka J. Vrednosti najnižjih pretokov (pod 5 ml/min) smo povzeli iz ročnih meritev oz. smo najnižje pretoke preračunali iz natekle količine vzorca v časovnem intervalu.

Na stalnem kapljanju L sem v okviru predhodnih meritev, občasnih meritev v letu 2002 ugotavljala, da mu pretok prek leta niha med 0 in 6 ml/min. Ker nismo imeli na razpolago merilnika nivoja z dataloggerjem za zvezno merjenje pretoka, sem si pomagala s starim evaporimetrom z mehansko uro, ki sem ga ustrezno opremila s posodo z natego in ga tako priredila za meritve pretoka. Vsakokrat izteklo vodo iz natege smo zbirali v večji posodi (Sl. 5). S sicer zamudnim odčitavanjem s papirnega zapisa, preračunavanjem pretokov in kontrolo tako dobljenih vrednosti s količino iztekle vode v zbirni posodi, sem dobila hidrogram tudi za to kapljanje. Izkazalo se je, da je kapljanje L stalno.

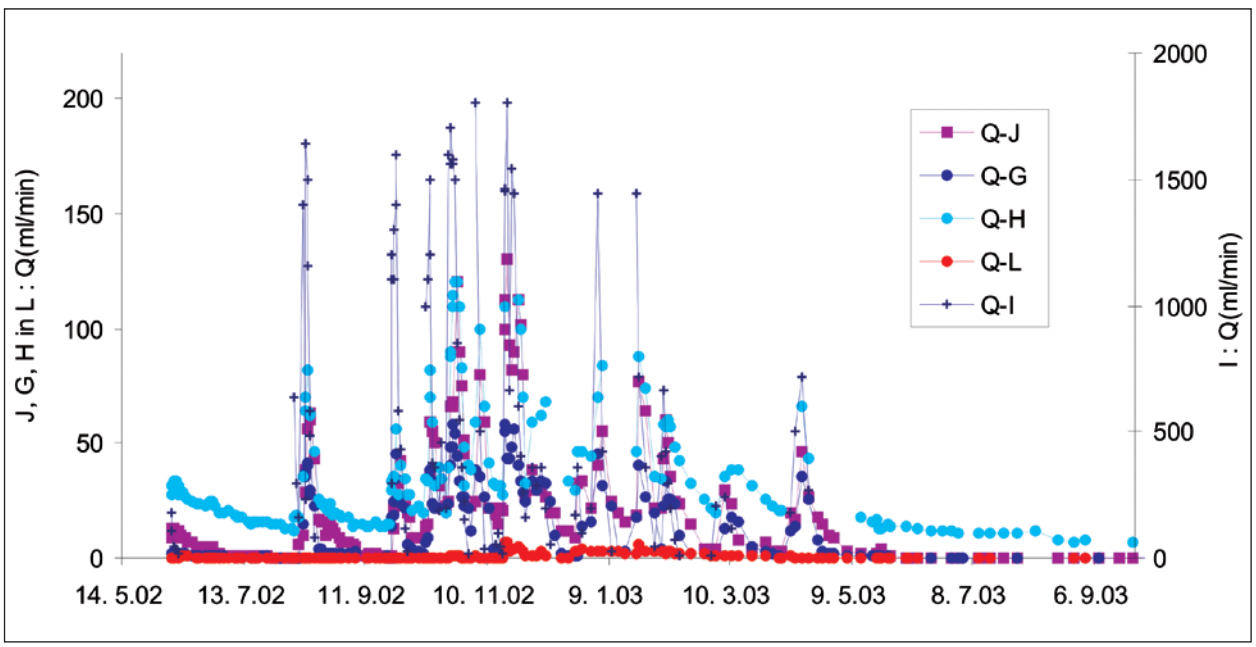
REZULTATI

OBČASNE MERITVE PRETOKA

Meritve pretokov curkov do dvakrat dnevno so pokazale osnovne značilnosti curkov. Iz slike 6 je razvidno, da so bili največji pretoki curkov v hidrološkem letu 2002/03 novembra 2002 in da curek I po izdatnosti odstopa od drugih curkov. Prvi tip curkov so tisti curki z velikim nihanjem pretoka, kot sta curka E (Sl. 7B) in curek I (slika 6), ki je dosegal pretok do 1800 ml/min. Hitremu naraščanju pretoka je sledil tudi hiter upad do minimalnih vrednosti oz. presušitve.

pretoka pa je upočasnjeno. Ti curki tudi v daljših sušnih obdobjih ohranjajo sorazmerno velik pretok, kar kaže na obsežnejšo mrežo slabo prepustnega dela zaledja curkov, ki se odraža v počasnem praznjenju zaledja, kar pomeni, da taki curki pomembno prispevajo vodo v daljših sušnih obdobjih. Seveda je tu še cela vrsta curkov, ki bi jih uvrstili med ta dva tipa.

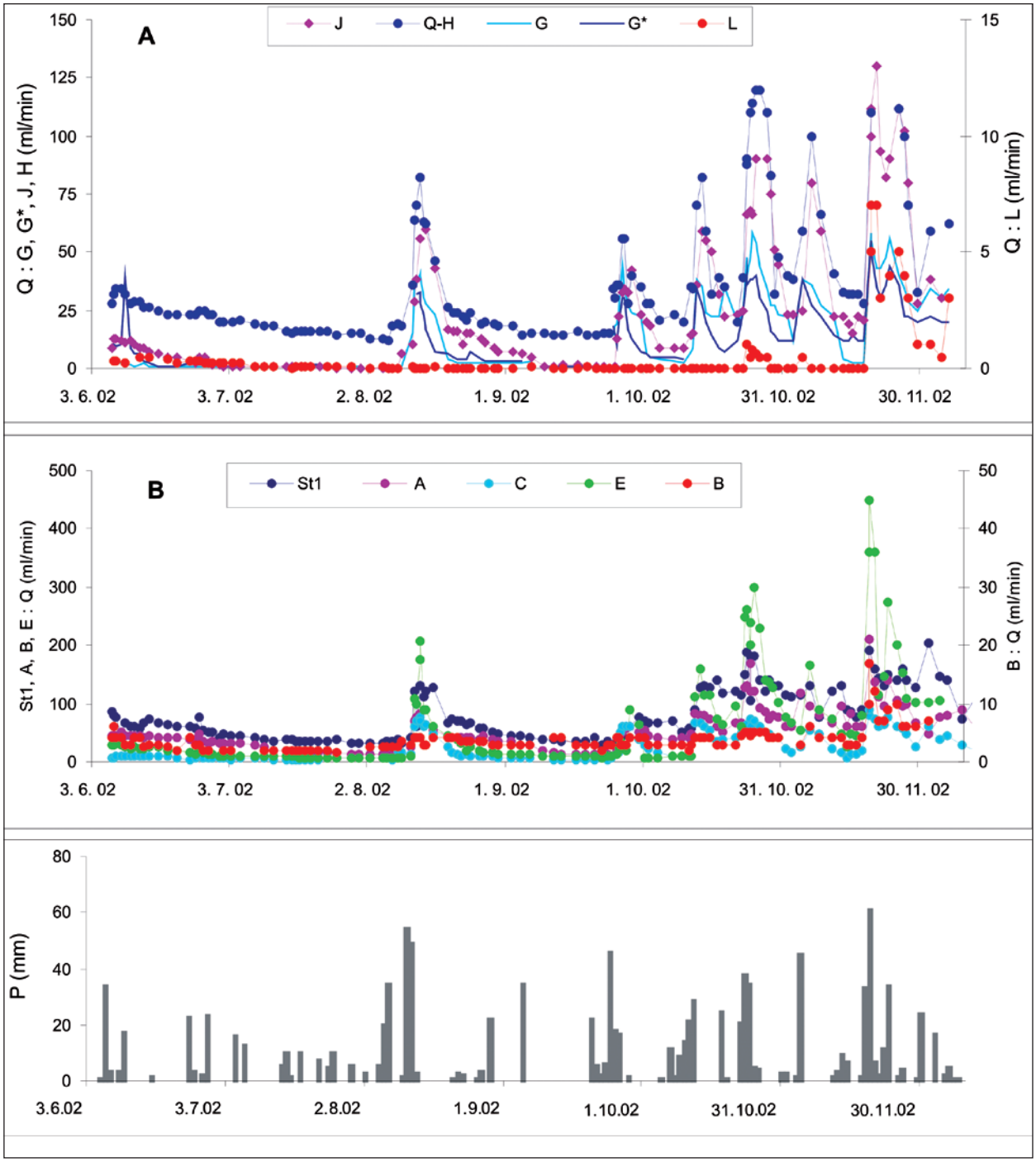
Izstopajo majhna kapljanja oz. kapljanja s pretokom nekako do 15 ml/min, kot sta točki B (Sl. 7B) in L (Sl. 7A), v katerih se infiltrirana voda, ki se v zgoraj omenjenih curkih



Sl.6: Ročne meritve pretokov v hidrološkem letu 2002/03.

Fig. 6: Manual discharge measurements in hydrological year 2002/03.

Drugi tip so curki, ki jim pretok med letom najmanj niha, kot sta curek H s (Qmax/Qmin=18) in delno J (Sl. 7A) ter curek St1 (Qmax/Qmin=7) ((Sl. 7B). Vodni valovi so zaobljeni brez nihanj pretoka, upadanje odrazi v vodnih valovih, določeno obdobje le shranjuje v njuno zaledje, dokler ni dovolj zapolnjeno, da sledeče padavine sprožijo oblikovanje izrazitega, mesec in več časa trajajočega vodnega vala s počasnim upadanjem pretoka.

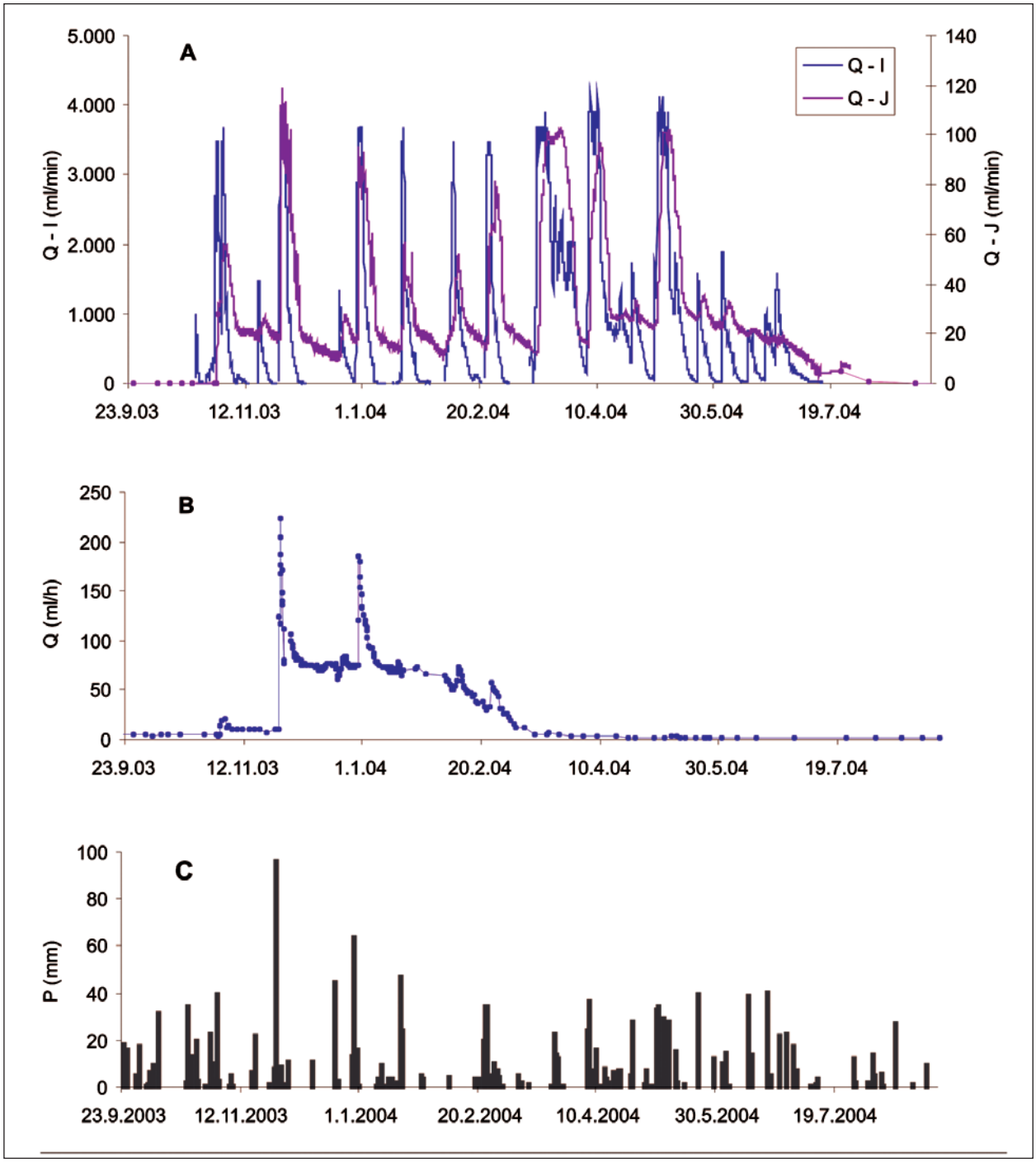


Sl. 7: Meritve padavin in ročne meritve pretokov curkov v Kristalnem rovu in pred njim (A) ter pretokov curkov v Glavnem rovu pred Razpotjem (B).

Fig. 7: Measurements of precipitations and discharges of trickles in Kristalni rov (A) and trickles in Glavni rov in front of Razpotje (B).

ZVEZNE MERITVE PRETOKA

Podrobnejšo sliko smo pridobili šele z zveznimi oz. pogostimi meritvami pretoka (vsakih 15 min), s katerimi smo začeli poleti 2003. Sočasne meritve padavin na površju so podale razporeditev in količino padavin za isto obdobje (Sl. 8C). Iz hidrograma curka I za hidrološko leto 2003/04 je razvidno, da je curek kar 5-krat presahnil (Sl. 8A), sicer pa oblikoval strme vodne valove z maksimalnimi pretoki okoli 4000 ml/min. Osrednji del vodnih valov je trajal

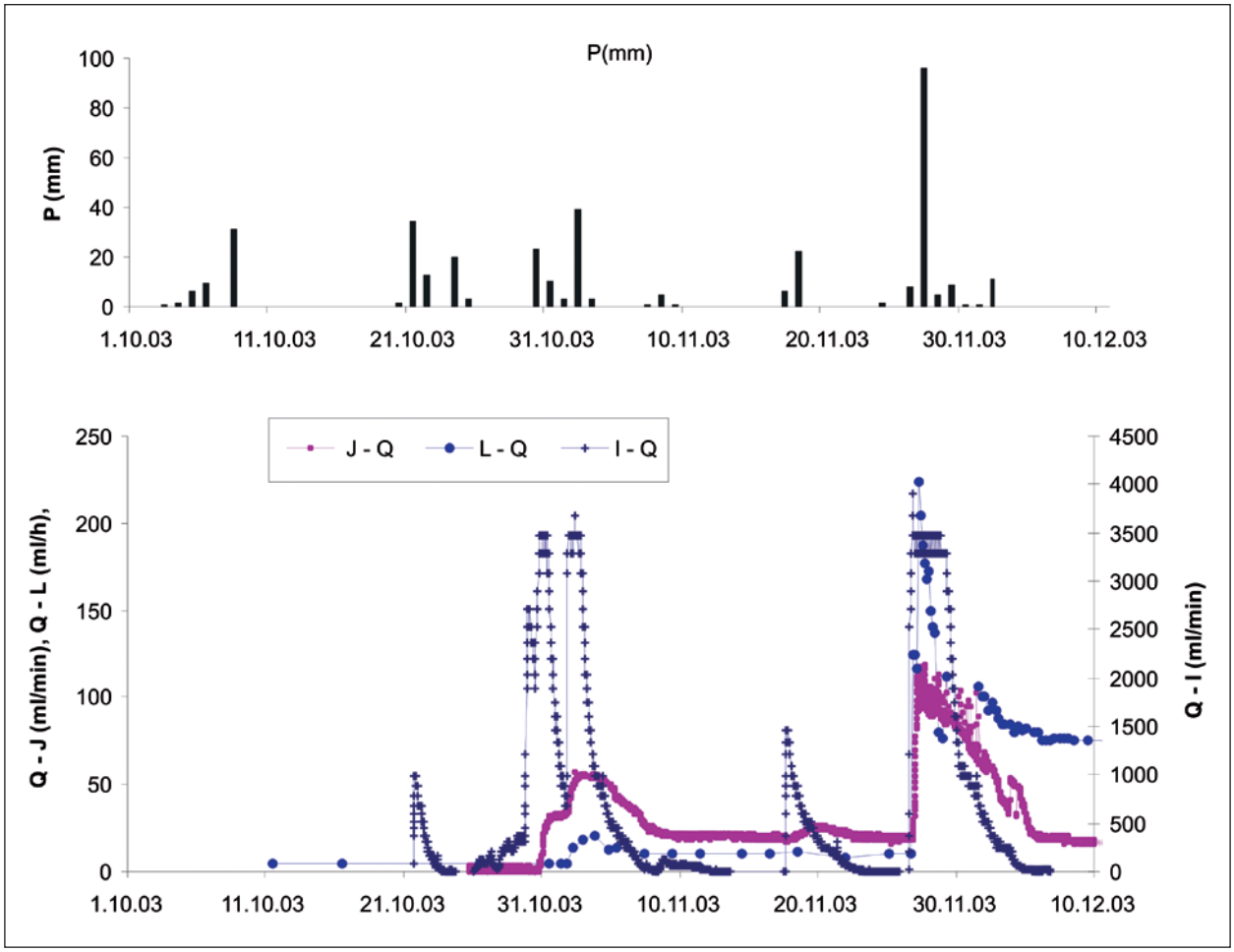


Sl. 8: Zvezne meritve padavin (C) v hidrološkem letu 2003/04, hidrograma curkov I in J (A) ter hidrogram kapljanja L (B).

Fig. 8: Continous measurements of precipitation (C) in hydrological year 2003/04, hydrogrammes of trickles I and J and hydrogramme of dripping point L.

okoli 1 teden, po nekaj nadaljnjih dneh pa je curek v primeru, da ni bilo novih padavin, presahnil.

Zvezne meritve pretoka curka J so pokazale, da je stalen, in da dosega v obdobjih, ko curek I presuši, zelo nizke vrednosti pretoka. Ko je curek I oblikoval velike vodne valove, so se oblikovali vodni valovi tudi v curku J, vendar različno obsežni, medtem ko so manjši izostali (Sl. 8A). Vodni valovi curka J so trajali opazno dlje kot pri curku I, upadanje pretoka v vodnih valovih pa je bilo upočasnjeno. Minimalni pretoki med vodnimi



Sl. 9: Reakcija curkov I, J in L na padavine po daljšem sušnem in v »namočenem« obdobju.

Fig. 9: Reaction of trickles I, J and L to precipitation after a longer dry period and in wet period.

valovi niso nikoli upadli pod 12 ml/min, počasnemu upadanju pretoka po zadnjem izrazitejšem vodnem valu v hidrološkem letu je sledilo eno-mesečno obdobje najnižjih pretokov s komaj zaznavnim upadanjem pretoka do konca hidrološkega leta.

Hidrogram kapljanja L je bil bistveno drugačen od hidrogramov curkov I in J (Sl. 8B). Razvidno je intenzivnejše iztekanje vode v edinem vodnem valu v hidrološkem letu, ki je trajal skoraj tri mesece z dvema izrazitima, kratkotrajnima porastoma pretoka, ki sta nastopila sočasno kot povišanja pretoka v curku J. Sledilo je počasno upadanje pretoka, čeprav so sledile še intenzivne in izdatne padavine, ki so v curku I oblikovale največje vodne valove v hidrološkem letu 2003/04. Upadanju pretoka je sledilo obdobje najnižjih pretokov, ki je trajalo kar 4 mesece, ko je pretok minimalno, komaj zaznavno upadal.

Ti podrobnejši hidrogrami curkov so nam omogočili tudi boljši vpogled v začetek reakcije pretokov posameznih curkov po padavinah. Opazne so bistveno različne reakcije pretoka posameznih curkov na padavine po daljšem sušnem poletnem obdobju ter opazno manjše razlike v času dobre namočenosti zaledij. Da gre za bistveno različen način pretakanja v sušnih razmerah in v razmerah dobre namočenosti prsti in zapolnjenosti zaledij curkov z vodo, so pokazali že sledilni poskusi na tem območju (Kogovšek 2000, Kogovšek & Šebela 2004).

Take večje razlike v reagiranju curkov na padavine smo zabeležili pri oblikovanju vodnih valov konec oktobra 2003 po dolgem poletnem sušnem obdobju, ob taljenju snega marca 2004, ko so mesec dni pred tem ob obilni snežni odeji prevladovale nizke temperature in v začetku maja 2004, ko je curek J že dalj časa dosegal sorazmerno nizek pretok, zaradi sorazmerno visokih temperatur in prebujajoče se vegetacije pa je evapotranspiracija zmanjševala količino efektivno infiltriranih padavin.

Iz slike 9 je razvidna reakcija curkov konec oktobra po skoraj 5-mesečnem sušnem obdobju. Predhodno

hidrološko obdobje se je dejansko zaključilo konec maja 2003, ko je curek I presušil, curka J in L pa sta dosegala nizek pretok, ki je nato ob minimalnih nihanjih vztrajal do konca oktobra. V tem 5-mesečnem obdobju je padlo 470 mm dežja, od katerega se ga je 200 mm shranilo v zaledju curkov (Petrič 2001).

Dne 20. in 21.10.2003 je padlo 34 in 13 mm dežja, ki je povzročil šibko reakcijo pretoka le pri curku I. Čez 3 dni je padlo še 23 mm dežja, ki je ostal brez reakcije pretokov. Od 29.10. zvečer do 31.10. zjutraj je padlo še 36 mm dežja, ki je sprožil izrazito reakcijo curka I. Njegov pretok je začel naraščati skoraj sočasno s padavinami in začel upadati, ko so padavine prenehale. Reakcija pretoka J je zaostajala za curkom I kar za 29 ur. Kasneje, 1.11.2003 popoldne je padlo skoraj 40 mm intenzivnega dežja, ki je sprožil pri curku I oblikovanje novega izrazitega vodnega vala, pri curku J pa hitrejše naraščanje pretoka v prvem vodnem valu, ki se je začel oblikovati v prvih urah 31. oktobra. Te padavine so bile zadostne, da je skromno reagiral tudi curek L, in sicer dva dni za curkom J in več kot 3 dni za curkom I. Pretok curka I je najhitreje upadel, curek J je upadal počasneje in enako kot curek L nato vztrajal na pretoku, višjem od izhodnega.

V dneh 16. in 17. novembra je padlo še 29 mm dežja, na katerega je podobno kot 21.10. reagiral le curek I, curek J pa komaj zaznavno. Sledil je intenziven dež, ko je popoldne 26.11.2003 padlo kar 96 mm dežja, ki je sprožil takojšnje oblikovanje izrazitih vodnih valov pri vseh treh curkih (Sl. 9). Pretok curka I je reagiral že 16. novembra ob 16.00, curka J in L pa približno 6 ur kasneje.

Meritve jasno kažejo, da v primeru dobre namočenosti zaledij curkov reagirajo različni tipi curkov sorazmerno hitro in brez večjih razlik, medtem ko je praznjenje njihovega zaledja oz. njihov prispevek vode v vodonosnik tedaj bistveno različen. Medtem, ko je curek I po doseženem maksimalnem pretoku v 4 dneh upadel do minimalnega pretoka, v nadaljnjih 2 dneh pa presahnil, je curek J le počasi upadal in se ustalil ob le počasnem upadanju na pretoku, ki je znašal dobro desetino maksimalnega pretoka, curek L pa podobno na vrednosti dobre tretjine svojega maksimalnega pretoka. V naslednjih dveh tednih sta torej prispevala vodo v vodonosnik le ta dva tipa curkov, saj je bil curek I suh. Do podobnih razmer je prišlo v hidrološkem letu 2003/04 kar 5-krat.

ZAKLJUČKI

Celoletne občasne meritve pretoka curkov v jami tudi do dvakrat dnevno so podale le osnovno sliko dogajanja v hidrološkem letu in različne tipe curkov. Kasnejše zvezne meritve pa so pokazale na celotno dogajanje v vseh podrobnostih, posebno na dogajanje v vodnih valovih ob različnih hidroloških razmerah, ko so spremembe lahko zelo hitre, kot tudi dogajanje ob tistih najnižjih pretokih. Zelo različni hidrogrami curkov za hidrološko leto 2003/04 so nakazali, da so za dobro osnovno poznavanje dinamike pretakanja potrebne zvezne meritve, ki potekajo vsaj eno hidrološko leto.

Meritve treh različnih tipov curkov so pokazale, da se v daljših poletnih sušnih obdobjih padavine lahko ne odrazijo v povečanju pretokov curkov, ampak se le shranjujejo v njihovem zaledju. V letu 2003 v poletnem 5-mesečnem sušnem obdobju se občasne padavine, tudi intenzivnejše padavine do 45 mm, niso odrazile v povečanjih pretokov curkov, ampak so se infiltrirale v zaledje (200 mm) in tam shranile. Prva reakcija curkov po takem obdobju je bila zelo različna glede na tip curka. Najhitreje so reagirali curki, ki jim pretok najbolj niha in ki oblikujejo strme vodne valove s hitrim upadanjem pretoka. Pretok stalnih, večinoma maj izdatnih curkov, je reagiral 29 ur do 3 dni kasneje in oblikoval dalj časa trajajoče vodne valove s počasnim upadanjem pretoka. V namočenih obdobjih so vsi curki na padavine reagirali hitro in brez večjih razlik, kar kaže na pomemben vpliv namočenosti zaledja na pretakanje vode in prenos topnih kontaminantov skozi vadozno cono krasa. Bistvena razlika med curki se kaže v načinu polnjenja, predvsem pa praznjenja njihovega zaledja, kar zavisi od značilnosti njihovega zaledja; kar so delno že nakazale raziskave s podrobnim geološkim kartiranjem (Kogovšek & Šebela 2004). Stalni curki s počasnim praznjenjem ter curki in kapljanja, ki se izrazito praznijo le občasno v obliki dolgo trajajočih vodnih valov, pomenijo pomembno napajanje vodonosnikov tudi v daljših sušnih obdobjih. Na dinamiko pretakanja vode pa je vezan tudi prenos kontaminantov.

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RAINWATER PERCOLATION DYNAMICS ASSESSMENT THROUGH THE VADOSE KARST ZONE ON THE BASIS OF DISCHARGE MEASUREMENTS

Summary

Periodical measurements, up to twice per day, of eleven trickles in Kristalni (Crystal) and Glavni (Main Channel) Rov of Postojnska Jama (Fig. 1) in the hydrological year 2002/2003 registered different types of trickles (Fig. 6 and 7). We stated that there are differences among the trickles at formation of water pulses during various hydrological circumstances but twice per day measurements were not sufficient for a detailed judgment. This is why we have chosen three typical trickles for further researches: trickle I with discharge of more than 1000 ml/min, a smaller trickle J with discharge up to 130 ml/min and dripping L with discharge up to 6 ml/min (Fig. 1) and in the hydrological year 2003/04 we continuously measured their discharge. At the same time we monitored the distribution and quantity of precipitations on the surface above the trickles (Figs. 2 and 8C).

These continuous measurements registered the entire activity in all the details and in particular the incidents in water pulses during different hydrological conditions, when the changes may be very quick but also what is going on during the lowest discharges. Extremely varying hydrogrammes of trickles for the hydrological year 2003/04 point out that good knowledge of percolation dynamics requires continuous measurements lasting one hydrological year at least.

Measurements of I, J and L (Fig. 8) have shown that in longer summer dry periods the rainfall does nor reflect in an increased discharge of trickle but it is stored in their recharge area. In a summer 5 months long dry period (in 2003) periodical rainfall did not in trickle increase but the rain was infiltrated in recharge area (200 mm) and stored there. The first trickle reaction after such a period was varying with regard of trickle type (Fig. 9). The fastest was reaction at trickles with the most oscillating discharge and these shaping steep water pulses togehther with fast discharge decrease. In a wet period all the trickles reacted fast and without noticeable differences to precipitations showing an important influence of soaked recharge area on flow and transport of soluble contaminants through the vadose zone of karst. Essential difference among trickles is shown in emptying of their recharge area. Permanent trickles with slow emptying and trickles and drippings that empty just seasonally in a form of a long lasting water pulses, present an important aquifer feed even in longer dry periods.The transport of contaminants is also controlled by the dynamics of water discharge.

COBISS: 1.01

CONTRIBUTION OF SIMPLE HYDROGEOLOGICAL INDICATING METHODS IN CONTAMINATION-IMPACTED ENVIRONMENTS

UPORABA METODE PREPROSTIH HIDROGEOLOŠKIH INDIKATORJEV V ONESNAŽENIH OKOLJIH

Slavomír MIKITA[1] & Vladimír VYBÍRAL[2]

Abstract UDC 556.3:504

Slavomír Mikita & Vladimír Vybíral: Contribution of simple hydrogeological indicating methods in contamination-impacted environments

Under the project of Ministry of the environment of Slovak Republic a "real" impact of various contaminant sources on water was monitored and assessed during the period of 4 years. Various geological environments of The Western Carpathians were chosen as studying areas. The results of the project confirm that the influence of the contamination source is variable in space and time. An amount of objective and efficient information is necessary to fulfill the requirements for the water treatment. The possibility how to minimize the amount of expensive and intricate methods used by investigation was to connect them with hydrogeological indicating methods (HIM). The correlated relations distinguished between contaminant and physical characteristics of water allow using the obtained local information in larger area and repeating them in higher frequency. The economical benefit is relative to increasing demands on space and time. The base was built on the water conductivity and water temperature measurements set in field. The measured values which were processed basically allow obtaining indirect information about the contamination spreading. By correlation the values with water analyses for a monitoring site from specific studied locality and by added other information from field methods the results can be amplified. It is possible to substitute the intricate and expensive contaminant spreading mapping methods by HIM and monitor the dynamic changes of contamination influences in space and time with denser data net.

Key words: contamination, environment, conductivity, water temperature, information.

Izvleček UDK 556.3:504

Slavomír Mikita & Vladimír Vybíral: Uporaba metode preprostih hidrogeoloških indikatorjev v onesnaženih okoljih

V okviru projekta slovaškega ministrstva za okolje, smo v obdobju štirih let izvajali raziskave vpliva različnih virov onesnaževal na vodne vire. Izbrali smo več področij z različno geološko sestavo v zahodnih Karpatih . Rezultati so potrdili, da je vpliv virov onesnaženj spremenljiv v prostoru in času, zato učinkovita zaščita vodnih virov zahteva veliko prostorsko in časovno gostoto informacij in raziskav. Da bi pri tem zmanjšali uporabo dragih in zapletenih metod, smo uporabili metodo hidrogeoloških indikatorjev (HIM), ki temelji na osnovi povezave med koncentracijo onesnaževal in osnovnimi fizikalnimi parametri vode, kot sta temperatura in specifična električna prevodnost. Merjenje teh parametrov omogoča posredno zaznavanje onesnaževal. Če njihovo zvezno opazovanje združimo s točkovnimi analizami vode in ostalimi terenskimi metodami, lahko vzpostavimo učinkovito in cenovno ugodno kartiranje širjenja onesnaževal.

Ključne besede: onesnaževanje, okolje, specifična električna prevodnost, temperatura vode, informacije.

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INTRODUCTION

The requirements for water quality protection have a very high priority. To protect the water contamination must be clearly detected, considered and predicted. Specific localities were studied with aim to improve knowledge about transport of contaminants and behaving the contamination-impacted environments.

Contamination-impacted environments in this case can be characterized as localities where the source of contamination has an influence on their vicinity with significant changes in water quality. The most common kind of contamination-impacted environments in Slovak Republic present an "old" landfills often built without legislative control and sufficient information about the waste storage. Under the project of Ministry of the Environment of Slovak Republic a "real" impact of 15-selected landfills on specific geological setting of The Western Carpathians was studied during the period of 4 years (Vybíral *et al.,* 2005).

In "old" landfills where all types of materials have been deposited and are possible source of various kinds of organic and inorganic pollutants, originated in leaching process. Landfill leachate is generated by excess rainwater percolating through the waste layers. Combined physical, chemical and microbial processes in the waste transfer pollutants from the waste materials to the percolating water. Focusing on the common type of landfill receiving a mixture of municipal, commercial and mixed industrial waste, but excluding significant amounts of concentrated specific chemical waste, landfill leachate may be characterized as water based solution of four groups of pollutants (Christensen *et al.,* 2001).

- Dissolved organic matter, expressed as Chemical Oxygen Demand (COD) or Total Organic C (TOC), including CH_4, volatile fatty acids and more refractory compounds for example, fulvic-like and humic-like compounds,
- Inorganic macrocomponents: Ca, Mg, Na, K, NH_4^+, Fe, Mn, Cl, SO_4^{2+}, HCO_3^- ,
- Heavy metals: Cd, Cr, Cu, Pb, Ni and Zn,
- Xenobiotic organic compounds (XOCs) originated from household or industrial chemicals are present in relatively low concentrations in the leachate (usually less than 1 mg/l of individual compounds). These compounds include among others a variety of aromatic hydrocarbons, phenols and chlorinated aliphatics.

Other compounds may be found in leachate from landfills: e.g. B, As, Se, Ba, Li, Hg and Co. But in general these compounds are found in very low concentrations and are only of secondary importance.

Leachate composition varies significantly among landfills depending on waste composition, waste age and landfilling technology.

Where leachate enters the groundwater, significant changes in water quality are observed and complicated biogeochemical patterns develop in the leachate pollution plume.

The fate and behaving of contaminants will depend on many factors, like individual characters of contaminants or hydrogeological conditions of given environment. In this system various chemical, biochemical and physical processes are running and the chemical equilibrium is changing. One of the main characteristic manifestations related to the contaminants spreading from the landfill is the presence a sequence of redox zones in the groundwater. They originated from leachate reducing processes with methanogenic conditions close to the landfill and oxidized conditions in the outskirts of the plume.

The aim of the project was also to present the optimal methods for investigation and monitoring of the contaminant spreading in specific environments. From the view of contamination spreading mapping and monitoring is necessary to get information about (Šráček *et al.,* 2000):

- nature of the contaminants, source and way of contamination,
- area and rate of contamination, including the background values that are valid for specific localities,
- migration parameters, direction and velocity of contamination spreading, characteristics of the contaminated environment (porosity, granularity), hydrogeological parameters, groundwater regime,
- history of contamination and its development in time, trends of contamination differences,
- evaluation of the objects endangered by contamination spreading, the level of their endangerment, the necessity and propose of remediation methods.

To get answers to most of these questions is only possible by studying the interaction zone – the zone of real influence of the source of contamination on their vicinity (Fig. 1).

Zone of interaction is dynamic in space and time; it depends on the water regime, the characteristics of landfill material, the maturity of stored material and engineering geological and hydrogeological conditions.

For the approach to solve the project it was useful to distinguish the landfills due their characteristic zone of interactions with aquatic environment (Putiška et al., 2005). Four main models of landfills can by presented: **a)** model with zero thickness of superincumbent bed (or

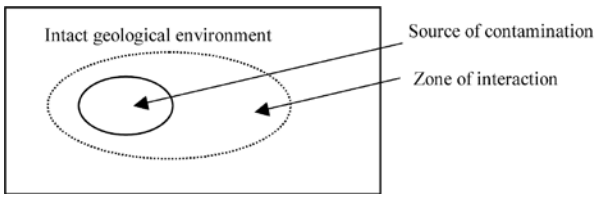

Fig. 1: Model of interaction.

landfills of "valley type"), **b)** model with the impermeable subsoil in 10-14 m depth, **c)** model with impermeable subsoil in „endless" depth, **d)** model of landfill encapsulated by slurry trench walls.

For the landfill locallizated on karst the model with impermeable subsoil in „endless" depth can be applied. In this case landfill is deposited directly on the permeable environment; vertical movement of groundwater is unlimited. Landfill material is deposited into natural or artificial depressions, as well as, onto the natural surface. Contamination is carried out from the landfill by infiltrating rainwater. The groundwater table is usually too deep for effective observation by boreholes and another methods are focusing on natural objects in the landfill vicinity (springs, rivers) therefore more suitable. Relative big differences of water quality in seasonal variations can be observed. Only one locality (DNV – Srdce) was situated on karst but obtained knowledge correspond well with the experiences from other countries, f. e. Slovenia (Petrič & Šebela, 2005), Sardinia (personal experience).

HYDROGEOLOGICAL INDICATING METHODS (HIM)

For the contamination spreading observation information about the water physical-chemical features around the contamination-impacted area are very important. The chemical analyses of water yield accurate information but they are not able to notice effectively frequent changes which depend on the influence of external (precipitation, air temperature) and internal (character and maturing of contamination, geology, hydrogeology) factors. The requirements on monitoring of the groundwater quality around the landfills has long-term duration (several tens years) and therefore demands on finances and expertise are necessary be taken into account.

There is a need for connecting them with simple but effective and operative mapping methods and subsequently getting more information about the contaminant spreading changes.

Presence and form of some typical chemical macrocomponents from landfill leaching in water is changing physical water parameters significantly and those are possible to be measured.

For mapping activities concerning contamination spreading the field measurement of physical parameters proved very well. Two parameters were measured – water conductivity and water temperature, both belong to Hydrogeological Indicating Methods (HIM).

The water conductivity (termed also as electrolytic conductivity - κ, given in $mS.m^{-1}$) is an important parameter in water geochemistry. It is a function of ion concentration in solution, their charge number, mobility and temperature. In waters, the contents of which is constituted mostly by inorganic compounds (drink waters, most of the surface- and some of waste water), the water conductivity can be used as the approximate rate of the mineral electrolytes concentration. In the wastewater that contains salts of organic acid and alkali the water conductivity is an approximate rate of the mineral content and organic electrolytes concentration (Pitter, 1999).

The water conductivity was measured:

• as an additional parameter with the targeted water sampling, at which only samples from the selected sampling places were taken, while in other places the orientation data about the range of contamination were obtained only indirectly,

• as a main parameter, when the water conductivity was the only measured parameter,

• continuously along the whole length of the borehole; observed were the changes in water conductivity in a water column.

Typical average values of water conductivity from measuring on specific localities ranged from 72 to 1043 $mS.m^{-1}$ (Fig. 2).

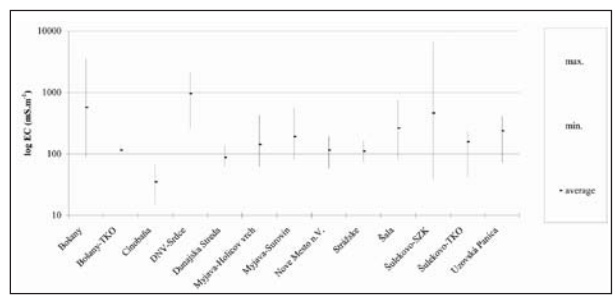

Fig. 2: The water conductivity value differences in the studied localities.

The differences between values were mostly dependent on character of contamination and its maturity, also on geological, hydrogeological and climate conditions. In some of studied localities there was strong influence from seasonality related to the amount of water in the environment (Fig. 3).

As a response there were frequently changing values during the year period. Stability of a frequency was also dependent on the depth of water circulation in the given environment. From the view of a longer time period (several years) the values had a decreasing, or an

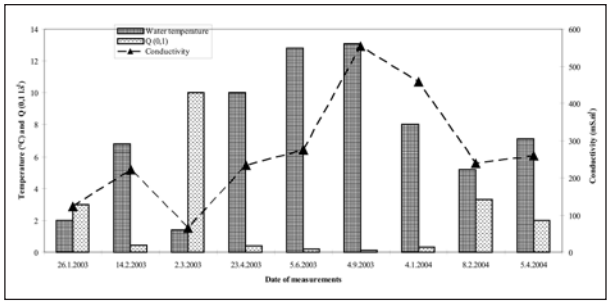

Fig. 3: Cooperation of the conductivity variation in concerning to water temperature and water quantity in one monitoring place of the given locality.

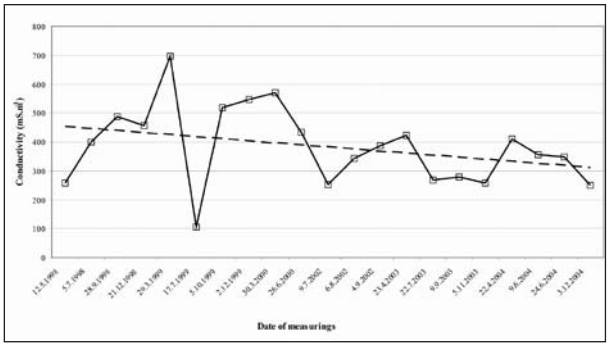

Fig. 4: Water conductivity development during a 6 years period in one of selected monitoring place from given locality.

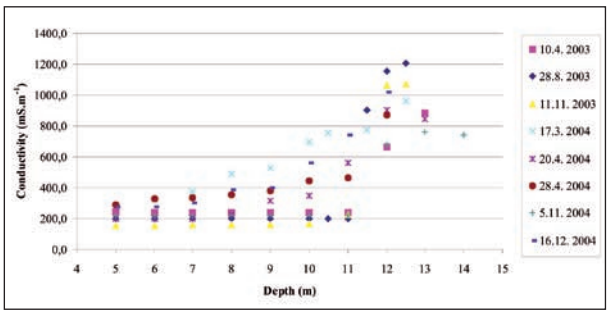

Fig. 5: Manifestation of the conductivity measurements in one borehole from given environment.

increasing trend, that was connected with the maturity processes in the deposited waste (Fig. 4).

Measuring the water temperature (**thermometry**) in the field is based on a values contrast. For the purposes of the contamination spreading mapping is depending mostly on the maturity processes in source of contamination where the organic matter is present. The water temperature could reach 40 – 60 °C. In this way is possible to use it for mapping of transport ways of contamination descending from source.

Water temperature was measured:

- directly in the field with each water sampling,
- for a special purpose, while doing an assessment of the origin of springs and ground water inflows into the streams.

PROCESSING AND EVALUATION OF MEASURED PHYSICAL PARAMETERS

Information obtained from water conductivity and water temperature measurements was processed basically and also was related to the results of other field methods to be amplified.

The basic processing came from screening all waters accessible in the studied area and it does recur in different time in the same positions. In this way it is possible to:

- assess the relative differences of water features in a studied area,
- map the source of contamination, and distinguish if the contamination is simple, long term, pointed, flatted, etc.,
- map the mass transport paths of contamination,
- estimate the trends of the measured data changes development (Fig. 4),
- detect the changes of the water vertical zonality continuance in the borehole (Fig. 5).

The information obtained according to described way has only relative character and their contribution is mainly by first investigation of the contaminant-impacted environment. The information with higher significance about the interactions in system contamination – water environment can be reached by the amplified processing. **The amplified processing** is based on distinguishing the correlation relations between the electric conductivity and a typical chemical parameter – the macrocontaminant – which is characteristic for the studied area and which we are considering to represent the physical attributes in the given environment. For that purposes the inert chloride affirm very well (Fig. 6).

Finding the optimal correlation relation is conditioned with character of contamination, geological and hydrogeological conditions of given locality. It is therefore necessary to apply the relation on specific monitoring place. The correlation allows substituting the specific chemical component with conductivity measurement and so extending the qualitative point information into space and repeating them in higher frequency. The new information with higher weight for the contamination spreading predictions can be obtained. According to the settings of the impacted environment the achieved information is a good assumption for various purposes:

- to monitor dilution with an increasing distance from the contaminant source (Fig. 7),
- to assess the climate and hydrological influences on contamination (Fig. 3),

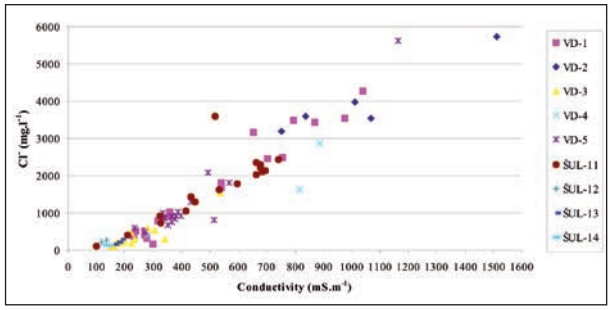

Fig. 6: Dependency between the chloride ions and conductivity from selected monitoring places in one of the studied locality.

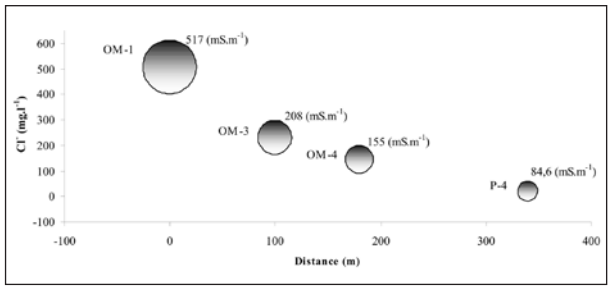

Fig. 7: Expression of a dependency between the parameters of chloride ions, conductivity and distance from contamination source, measured from the monitoring places of given locality.

- to describe the distribution of related components in space and time by developing 3D models (Fig. 8),
- to monitor the intensity and the rate of contamination (Fig 4,7,8),
- to predict the trends of contamination maturing processes (Fig. 3,4,5).

On the Fig. 8 are pointed the values that were detected in 6 boreholes from their water table to the bottom. The boreholes are localized in a front part of given landfill. The main groundwater flow is transverse direction on the boreholes.

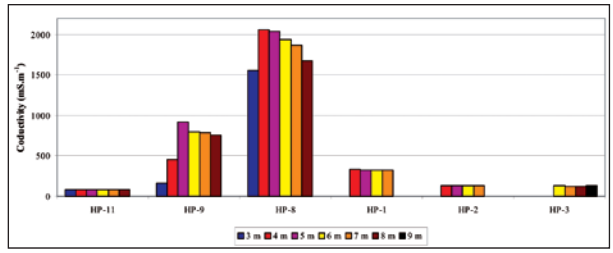

Fig. 8: Water zonality measuring in selected boreholes from one of studied locality.

The results after measuring and processing are possible to interpret also in a form of different outputs (Krčmář, 2002).

Application of HIM was utilized by dealing with the interaction between contamination-impacted environments and their surroundings with different extent of contribution (Mikita *et al.,* 2005). It is conditioned mainly by hydrogeological conditions of studied environment and the monitoring instruments access to the water. Relatively the best utilization was obtained from a landfill of "valley type" placed to the valley with impermeable or almost impermeable subsoil where the leakage from landfill is distributed to the surrounding area by outflow located in the front parts of landfills (Mikita *et al.,* 2005).

To observing the landfill influence on karst aquatic environment the HIMs can be mainly used for:

- discovering the hidden inflows of contaminants to the rivers, springs or wells present in the vicinity of the landfill,
- continuous monitoring for monitoring points in karst aquifers with caution for unfavorable situation, indirect monitoring of the seasonally differences in water quality.

CONCLUSIONS

Evaluation of a geological environment and contaminants interference is a complicated problem. The contamination spreading investigation and monitoring requires large amounts of data and detailed information about the surface, groundwater regime, water and soils physical and chemical characteristics. The danger from the given contamination-imapcted environment is radically changing in time and dimensional space. The 15 contamination-impacted areas situated in various geological units of Western Carpathians were analyzed in detail during the four years investigation.

Knowledge had shown that the intricate and expensive methods of mapping of contamination spreading and consequent monitoring can be substituted with simple but effective and operative hydrogeological indicating methods (HIM). Two physical parameters - water conductivity and water temperature were measured directly on monitoring sites. Values obtained from water

conductivity and water temperature measurements were basically processed and were also related to the results of other field methods to be amplified. Hydrogeological indicating methods in general allow:

- continual monitoring of excessively values changing,
- detection of potentially hidden transfer of contamination into the surface water,
- characterization of the depth of groundwater circulation in studied area,
- repetition of contamination spreading measuring in dimensional space and in time with relatively dense data net,
- monitoring extent and development of the contamination spreading according the changing condition.

The main advantage of HIM is their simplicity and possibility of the directly field measuring which allows sufficient and continual recording of values about the time and dimensional space variations in the contamination development.

The correlated relations between contaminant and water conductivity allow to extend local information from water analyses in larger area and repeating them in higher frequency.

An amount of objective and optimal amount of statistical information for the water protection management requirements can be obtained from HIM. It improves consideration possibilities for prompt answering how the contamination is dangerous, if is necessary to deal with the contamination and how is possible to handle with it in time.

Application of HIM can by utilized with different extent of contribution what is conditioned mainly by hydrogeological conditions of studied environment. For the landfills localized on karst the model with impermeable subsoil in "endless" depth can be applied. The investigation by HIM is here focus mainly on the springs and rivers present in the landfill vicinity.

The economical benefit from using HIM is rising also with the increase requirements on the longtime contamination spreading monitoring and the extent of studied area.

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GROUNDWATER VULNERABILITY OF THE KARST - FISSURE HYDROGEOLOGICAL STRUCTURE OF SOUTH – FACING SLOPES OF THE NÍZKE TATRY MTS., SLOVAKIA

RANLJIVOST PODZEMNE VODE V KRAŠKO-RAZPOKLINSKI STRUKTURI JUŽNIH POBOČIJ NIZKIH TATER, SLOVAŠKA

Erika KOVÁČOVÁ[1] & Peter MALÍK[2]

Abstract UDC 556.3:551.44 (437.6)

Erika Kováčová & Peter Malík: Groundwater vulnerability of the karst - fissure hydrogeological structure of south – facing slopes of the Nízke Tatry mts., Slovakia

An "intrinsic vulnerability" (according to Zwahlen *et al.,* 2004) to any contamination in general is considered using Malík´s extension (2005) of the Kullman´s method (2000), based on the assessment of the degree the rock disruption and karstification, affecting the shape of spring discharge recession curves. It is based on the presumption that the intensity of natural contamination attenuation processes depends on rock disruption/karstification. The method is applied on the Mesozoic rock environment of the most important hydrogeological structure in the southern slopes of the Nízke Tatry Mountains. Hydrograph analyses of groundwater depletion in the gauged or exploited springs were used for assessment of groundwater vulnerability to human and/or natural pollution. Differences in character of individual depletion hydrographs enable assessment an extent of absorption and elimination processes during the groundwater penetration through the rock environment from the infiltration area to the outflow in the spring or exploited source. The depletion hydrographs reflect not only the character (effect) of outflow area but reflect the effects whole infiltration and accumulation area. In total, 68 individual recession curves from 9 gauged springs were analysed. Obtained degrees of groundwater vulnerability are evaluated by 10 degree range of the Kullman´s vulnerability scheme, adjusted by Malík. The reached vulnerability values are consequently applied and assigned to the lithological types of discharge area of gauged springs. This study also describes an existence of individual laminar and turbulent sub-regimes that occur in the karts-fissure rock environment, the type of rock disruption from open micro– to macro fissures - to karst channels and subsequent estimation of the karstification degree.

Key words: groundwater vulnerability, sensitivity to pollution, hydrograph analyses, karstification degree, recession curves, Nízke Tatry Mts., Slovakia.

Izvleček UDK 556.3:551.44 (437.6)

Erika Kováčová & Peter Malík: Ranljivost podzemne vode v kraško-razpoklinski strukturi južnih pobočij Nizkih Tater, Slovaška

V članku obravnavamo ranljivost vodonosnika (v smislu Zwahlen *et al.,* 2004) na kakršnokoli onesnaženje z uporabo Malikove (2005) razširitve Kullmanove (2000) metode. Slednja temelji na obravnavi vpliva stopnje razpokanosti in zakraselosti kamnine na recesijo pretočnega hidrograma kraških izvirov. Metoda temelji na domnevi, da je naravno dušenje intenzitete onesnaženja odvisno od stopnje zakraselosti oz. razpokanosti kamnine. Metodo smo uporabili na območju sestavljenem iz kamnin mezocojskih starosti v najbolj pomembni hidrogeološki strukturi južnih pobočij Nizkih Tater. Na osnovi analiz recesijskih krivulj izvirov, ki jih izkoriščajo oz. jim merijo pretok, smo sklepali o stopnji absorbcije in drugih procesov izločitve onesnaževal med podzemnim pretakanjem vode. Recesijske krivulje ne odražajo le območje iztoka, pač pa celoten sistem pretakanja, vključno z infiltracijo in akumulacijo. Skupaj smo analizirali 68 recesijskih krivulj z 9 izvirov. Dobljene stopnje ranljivosti smo ovrednotili po 10 stopenjski lestvici in vrednosti uporabili na obravnavanih območjih glede na litologijo zaledja spremljanih izvirov. V študiji obravnavamo tudi območja laminarnih in turbulentnih tokov, ki se pojavijo v kraško razpoklinskem vodonosniku in tipe nezveznosti v kamninah, od mikro do makro razpok in kraških kanalov.

Ključne besede: ranljivost podzemne vode, občutljivost na onesnaženje, analiza hidrografa, stopnja zakraselosti, receijska krivulja, Nizke Tatre, Slovaška

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INTRODUCTION

The concept of groundwater vulnerability is based on the assumption that the physical environment may provide some degree of protection to groundwater again anthropogenic and/or natural impacts, and that degree of vulnerability is a function of the hydrogeologic setting and prevailing patterns of pollution (Vrba & Zaporozec, 1994; Ibe *et al.,* 2001). Vulnerability is regarded as an intrinsic property of a groundwater system that depends on the sensitivity of that own system to human and/or natural impacts.

Two types of vulnerability of groundwater were recognized by Daly *et al.* (2002): intrinsic and specific vulnerability. Definitions of these types of groundwater vulnerability were established in the framework of multilateral project of European hydrogeologists – „COST Action 620 - Vulnerability and risk mapping for the protection of carbonate aquifers". Not only these definitions, but also common understanding of the groundwater vulnerability factors were recognized within this project (Zwahlen *et al.,* 2004), and a set of methodical steps – a „European approach" of groundwater vulnerability assessment. Although primarily addressed to the karst rock media, this approach can be applied to all kinds of rock environments as it only extends assessments of some special features of karst environments (groundwater flow concentration) if exists (Malík & Švasta, 2004).

An **"intrinsic vulnerability",** evaluating a geological, hydrological and hydrogeological characteristics of site and does not depend on patterns of pollution.

A **"specific vulnerability"** is defined as a vulnerability of groundwater against specific contaminant or several contaminants caused by human activity.

The output of Kullman´s method (2000) using hydrograph analysis of groundwater depletion of the gauged springs can be marked as an „intrinsic vulnerability" as it does not recognize the specific properties of individual types of contaminants (heavy metals, pesticides, nitrates …). However, as it does not correspond in all aspects with the "standard European" definitions and approaches (Daly *et al.,* 2002, Zwahlen *et al.,* 2004), some authors (Malík, 2005) prefer to name this output as "groundwater sensitivity to pollution" to make clear difference between both concepts. The target Kullman´s method application in this case was the groundwater in the karst-fissure hydrogeological structure of the Nízke Tatry Mountains, Slovakia, located between the municipalities of Podbrezová, Krpáčovo, Jasenie and Lopej.

CHARACTERISTIC OF HYDROGEOLOGICAL STRUCTURE BETWEEN PODBREZOVÁ, KRPÁČOVO, JASENIE AND LOPEJ

The Nízke Tatry Mountains as the western part of the Carpathian arch are located in the north of Slovakia. The highest peak is Ďumbier with an elevation of 2,043 metres a. s. l. By geological structure, the Nízke Tatry Mts. belong to the "core-type" of mountain ridges, with a crystalline "core" and "envelope" built by autochthonous Mesozoic sediments plus several overthrusted units built also by Mesozoic sediments. The Mesozoic carbonate rocks, mostly various types of limestones and dolomites, are of Middle and Upper Triassic age. They represent one of the most important karst water resources areas in Slovakia.

Hydrogeological structure of the southern slopes of the Nízke Tatry Mountains between Podbrezová, Krpáčovo, Jasenie and Lopej (37.74 km^2 - Fig.1) is the most important natural groundwater reservoir with high quality drinking water, bound also to Triassic - Mesozoic rock environment. This highly permeable structure is about 1,200 metres thick. Considering the main geological units, the carbonate rocks in the structure belong to Hronikum unit with middle Choč nappe at the bottom, overlayed by two independent segments of upper Choč nappe. All these partial nappes are from the bottom to top built by the same lithology: Lower Triassic seiss and kampil layers (sandy shales and sandstones), Middle Triassic Gutenstein limestones, "Choč dolomites", reifling limestones, lunz layers (claystones and sandstones), Upper Triassic "main dolomites" - hauptdolomites, and dachstein limestones. All these layers have their equivalents in Ober Ost Alpine units in Austrian Alps. Under the Choč nappe, the Veporikum unit is placed as an underlying sequence of Mesozoic isolators and aquifers.

The hydrogeological structure itself has a very complicated hydraulic and hydrogeochemical system of groundwater flow, due to the several open fault systems. Complex tectonic settings of the area enabled a creation of three main hydraulic systems of groundwater flow (Fig.2), which were defined by Kullman (1983, 1990):

1. dynamic system of groundwater flow connected with the Hronský fault, a boundary fault of uplift of the Nízke Tatry Mts.,

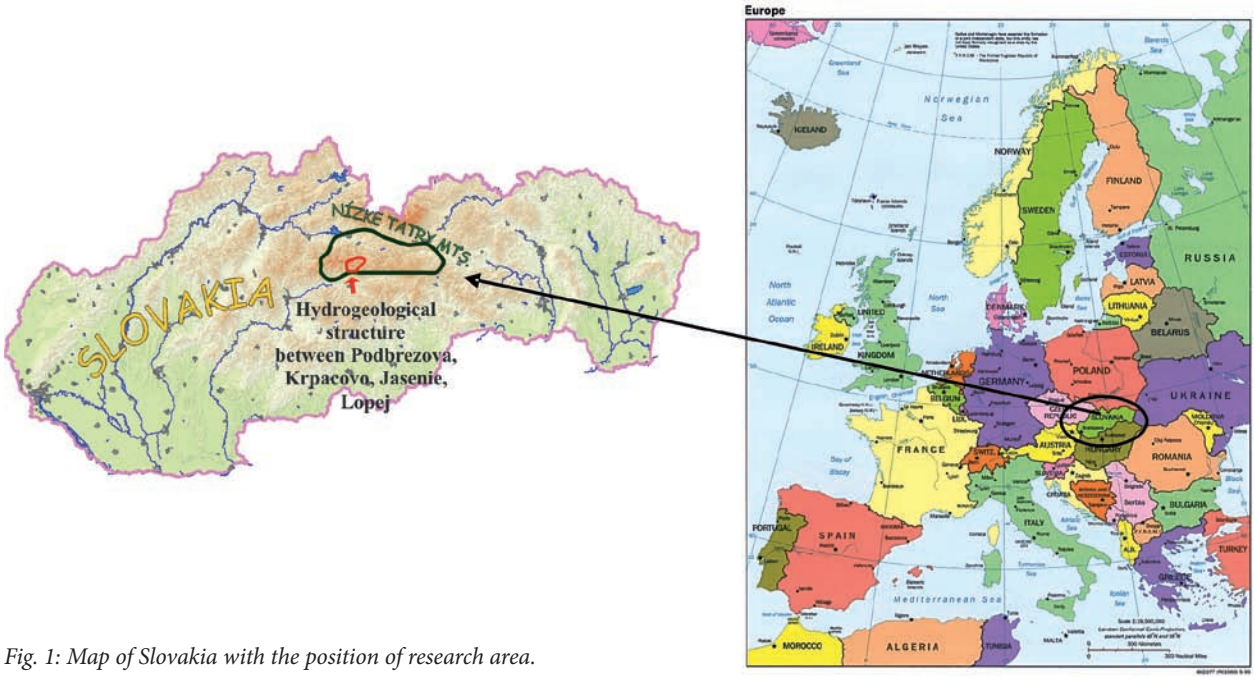

Fig. 1: Map of Slovakia with the position of research area.

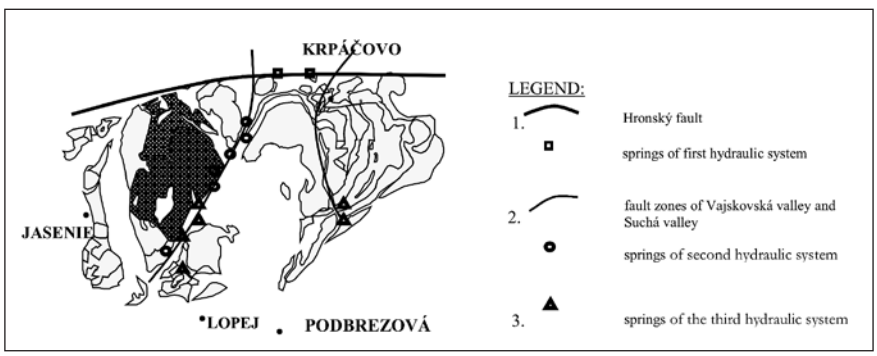

Fig. 2: Hydrogeological structure between Podbrezová, Krpáčovo, Jasenie and Lopej and three different hydraulic systems of groundwater flow.

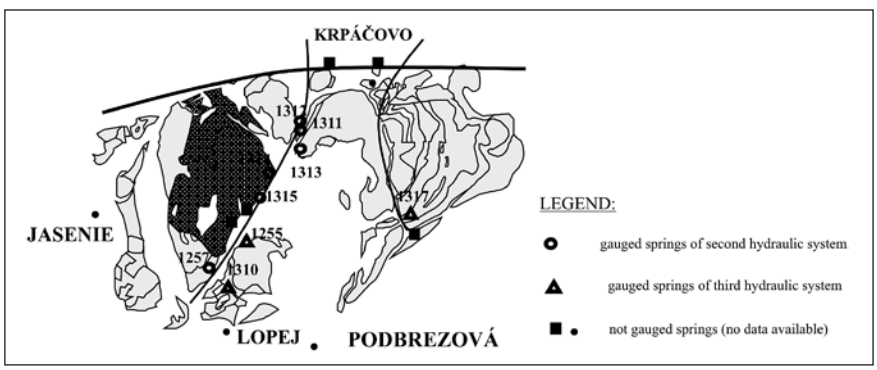

Fig. 3: Gauged springs of hydrogeological structure between Podbrezová, Krpáčovo, Jasenie and Lopej.

2. dynamic system of groundwater flow connected to transverse open fault zones cutting the structure along the Vajskovská and Suchá valleys – causing the circulation of the biggest groundwater amount, with quick and shallow movement,

3. inner system inside the hydrogeological structure itself - slower groundwater movement through the less disrupted parts of the hydrogeological structure.

The first hydraulic system – groundwater circulation controlled by the Hronský zlom fault is drained by 2 springs, in Krpáčovo and Tále area. In spite of its importance, this open fault hydraulic system could not be evaluated because of missing data of discharge time series. The second hydraulic system – transverse open fault zones passing Vajskovská valley and Suchá valley, is drained by 6 springs: **Spring of king Matthias** (No. 1257) in Lopej, **Uhlište** (No. 1311), **Vrabec** (No. 1312), **Horný 1, 2, 3** (No. 1313), **Horný 4** (No. 1314) a **Dolný** (No. 1315) in Dolná Lehota. The third hydraulic system (groundwater movement within hydrogeological structure) is drained by 6 springs, from which 3 data available (gauged) springs are **Hámor** (No. 1255), **Za**

továrňou (No. 1310) in Dolná Lehota and **Starý mlyn** (No. 1317) in Horná Lehota (Fig.3).

Estimated specific groundwater runoff of whole hydrogeological structure is ranging from 8.5 to 9.5 $l.s^{-1}.km^{-2}$ and the total sum of dynamic natural groundwater resources originating in the structure is 320 -359 $l.s^{-1}$(Kullman, 1983, 1990). Prognostic groundwater reserves (counting also external groundwater outputs) are estimated as 468 $l.s^{-1}$ (Hanzel *et al.,* 1990).

METHODS

The applied Kullman´s method (1997, 2000) adjusted by Malík (2005) is based on the assessment of the degree of groundwater vulnerability resulting from the rock disruption and karstification. Proposed vulnerability classification has 10 degrees of vulnerabilities assigned by differences in character of karstification and rock disruption signalized by individual depletion hydrographs. Differences in character of individual depletion hydrographs enable assessment of the anticipated possibility of reduction, absorption or elimination processes during the groundwater penetration through the rock environment.

Degree of vulnerability equal to 1 represent low vulnerability and only one laminar groundwater flow is present here. The risk of groundwater contamination is very low. The highest vulnerability equal to 10^{th} degree represents groundwater circulation exclusively in open karst channels, where only turbulent sub-regimes are present, without a mark of single laminar one. The risk of extensive groundwater contamination is very high. The highest vulnerability is then connected to developed karstification in large areas, with wide opened channels, swallow holes or sinkholes. Besides vulnerability, several other characteristics of rock environment, mainly the aperture of joints present, are influencing the final shape of recession curves: the existence of laminar or turbulent sub-regimes points out on the ratio of microfissures, macrofissures and open karst channels.

Discharge time series were analyzed for their decreasing parts, exceeding suggested threshold value of at least 8 weeks of uninterrupted decrease. From these, recessions possibly influenced by sudden precipitation events were excluded, as in spite of their decreasing character there is a danger of lowering the "decrease angle" on the hydrograph. Finally, a master recession curve was created by "best fit" simulation of the curve using the different starting discharge points of each subregime and 3 possible α depletion coefficients and 3 possible β depletion coefficients.

The method was applied on the Mesozoic rock environment – Triasic carbonates of Hronicum unit. In total, 68 recession curves from 9 gauged springs were analyzed. Final groundwater vulnerability degree of individual springs was based on the classification of the mean values of recession curve´s parameters – depletion coefficients α and β (Malík, 2005). Depletion coefficients also suggest on the type of groundwater flow regime. Coefficient α suggest a laminar regime of groundwater flow and coefficient β suggest a turbulent regime of groundwater flow. Each spring was characterised by its individual depletion coefficients and subsequent vulnerability (sensitivity to pollution) degree (Malík, 2005). The reached median value of the vulnerability degree was consequently applied also to different lithological types present in the discharge area of gauged springs. In this way, groundwater vulnerability of individual lithological types was defined. The outcome is the groundwater vulnerability map of studied hydrogeological structure. The same was done for individual hydraulic systems present in the Podbrezová – Krpáčovo – Jasenie – Lopej hydrogeological structure. Based on the recession characteristics of the springs bound to different hydraulic systems, mean groundwater vulnerability (sensitivity to pollution) degree of each hydraulic system was described.

RESULTS

GROUNDWATER VULNERABILITY AND REGIME OF GROUNDWATER FLOW OF INDIVIDUAL SPRINGS

The lowest vulnerability degree index of **2** was given to the **Starý mlyn** spring (No.1317) in Dolná Lehota. The analysis of depletion curves from weekly data of 30 years periods suggest an existence only one laminar regime of groundwater flow (Fig. 4). The risk of groundwater contamination is very low, is only general risk of surface entry of contamination into rock environment, with pos-

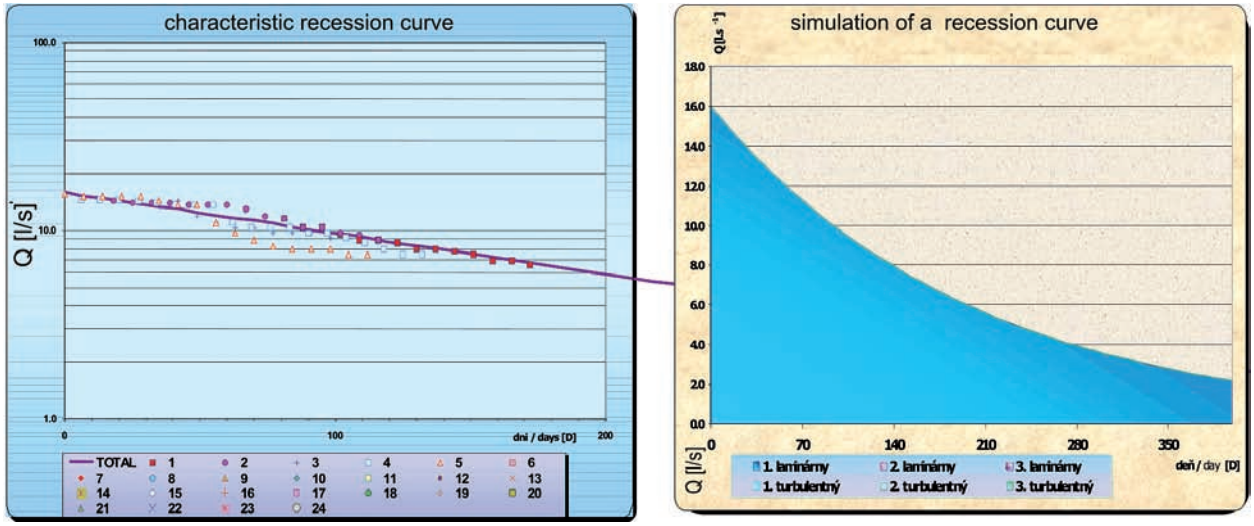

Fig. 4: Characteristic recession curve of spring No.1317 Starý mlyn in Dolná Lehota – lowest vulnerability (sensitivity to pollution) degree.

sibility of its great retention, fixation and dispersion. We can expect very low probability of significant contamination of groundwater source.

Higher vulnerability degree values – **2.5** and **2.7** – are reached by springs **Za továrňou** (No. 1310) and Hámor (No. 1255) in Dolná Lehota. Two laminar regimes are present here. Very low risk of groundwater contamination is present, but possibility of surface entry of contamination with its probable retention, fixation and dispersion is high. Probability of groundwater source contamination is very small, with exception of possible entry of contamination from closer vicinity (Kullman, 2000, Malík, 2005).

Spring **Horný 1, 2, 3** (No. 1313) reaches value **4** of vulnerability degree, and two laminar subregimes of groundwater are present here. Spring **Vrabec** (No. 1312) with value of vulnerability **4.3** has also two laminar subregimes. Spring **Horný 4** (No. 1314) in Dolná Lehota with vulnerability **5.0** suggest the combination of one laminar and one turbulent subregime of groundwater flow. This still means a low risk of groundwater contamination by surface entry into the rock blocks, but the possibility of significiant contamination point source with direct connection of the karst system to the surface exist. There is also still possibility of its retention, fixation and disper-

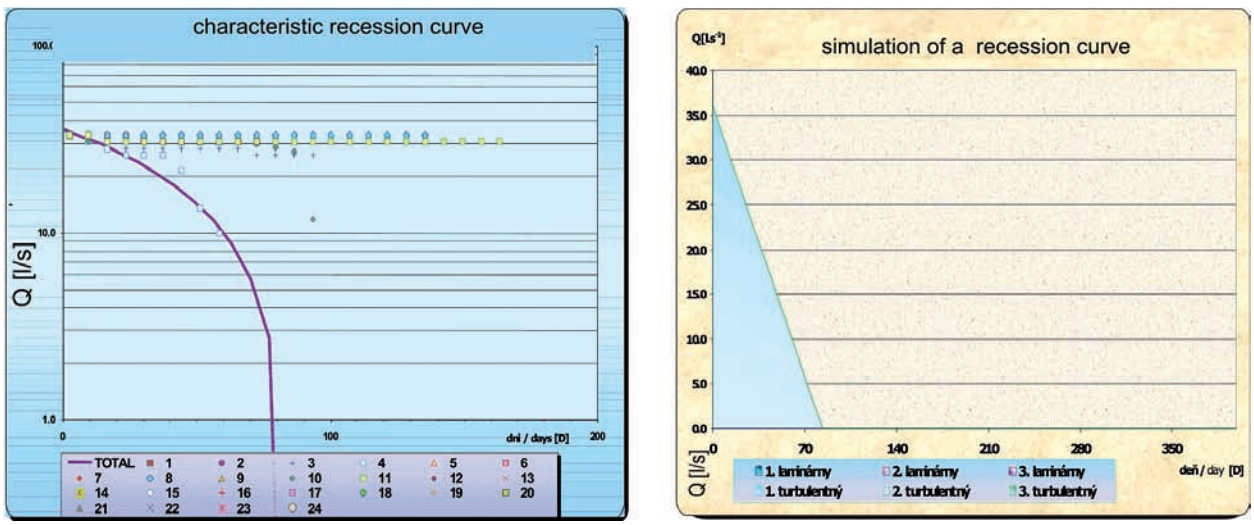

Fig. 5: Characteristic recession curve of spring No.1257 Spring of king Matthias in Dolná Lehota – highest vulnerability (sensitivity to pollution) degree.

sion of contamination, but point contamination sources represent a real danger to groundwater (Kullman, 2000).

More vulnerable seem to be spring **Uhlište** (No. 1311) and **Dolný** (No. 1315) in Dolná Lehota with vulnerability value **5.5** typical for karstic areas. Regime of groundwater depletion is composed by two subregimes with laminar flow and one subregime with turbulent flow. There is a limited possibility of its retention, fixation, but mainly dilution. Arrival of contamination to groundwater sources will be rather quick, but in lower concentrations, with longer duration period.

The higher vulnerability is determined for **Spring of king Matthias** (No.1257) in Lopej with vulnerability value **9** and existence of one turbulent regime of groundwater flow (Fig. 5). Possibility of groundwater affection by significant contamination point source with fast transport, low retention and dispersion is high. There is very high risk of groundwater contamination from far-away contaminant source and also fast increase of contaminant in groundwater source, with high concentration, but with limited duration period.

GROUNDWATER VULNERABILITY OF INDIVIDUAL LITHOLOGICAL TYPES

From existing depletion hydrographs of individual gauged springs is possible to define also a mean value of groundwater vulnerability (sensitivity to pollution) degree of individual lithological types, based on the mean characteristics of springs connected to these lithological types. There were enough data to evaluate four different lithological types – Choč dolomites, Gutenstein limestones, Hauptdolomites and carbonatic conglomerates of Vajsková. These lithological types are present in the discharge areas of gauged springs.

Choč dolomites show mostly laminar discharge sub-regimes and only sometimes turbulent sub-regime can by recognised. Substantial role in groundwater discharge has a sub-regime with laminar flow. The regime of groundwater discharge is based on differences in discharge curves and different discharge coefficient. The risk of more extensive groundwater contamination is low, with exception of close vicinity of the source. Degree of vulnerability according to Kullman´s classification (2000) adjusted by Malík (2005) reaches value of 3.3.

Conglomerates of Vajsková can by characterised by the presence of two laminar sub-regimes in spring hydrographs, from time to time a turbulent sub-regime can by present. Rock environment is characterised by irregularly developed fissure network, with majority of open macro-fissures. The risk of more extensive groundwater contamination is low. Value of groundwater sensitivity to pollution (groundwater vulnerability) of this rock environment reaches **4.1** degree of Kullman´s classification (2000) adjusted by Malík (2005).

Gutenstein limestones reach the vulnerability degree of **5.** Regime of groundwater discharge is composed from sub-regime of turbulent flow and laminar flow subregime. Substantial role in groundwater discharge has a sub-regime with laminar flow. Rock environment is characterised by an existence of crushed water-bearing zones or by dense network of open small fissures in combination with simple, partly phreatic conduit system of considerable extent. The risk of groundwater contamination by surface entry into the rock is low. There is a possibility of contamination increase by significant point pollution source with direct connection of the karst system to the surface.

"Main dolomites" – "hauptdolomites" reached the highest vulnerability **5.5** from 10 degrees range of used classification. This fact is quite interesting from the point of view of rock composition, but it also documents, that – on the contrary to the Mediterranian dolomite sequences – the Trassic dolomites in the Carpathian arc show a karstification potential and on many places are also strongly karstified. Regime of groundwater flow of the spring **Dolný** in Dolná Lehota is created by a superposition of two sub-regimes with turbulent flow and one sub-regime with laminar flow. We can assume higher risk of contamination by surface entry and also higher risk coming from possible point source of contamination.

GROUNDWATER VULNERABILITY OF DIFFERENT HYDRAULIC SYSTEMS OF THE HYDROGEOLOGICAL STRUCTURE ON THE SOUTHERN SLOPES OF THE NÍZKE TATRY MTS. BETWEEN PODBREZOVÁ, KRPÁČOVO, JASENIE AND LOPEJ

The first hydraulic system – Hronský zlom fault could not by evaluated because of insufficient data.

The second hydraulic system - an open fault zones passing the Vajskovská valley and Suchá valley, is in average characterised by one sub-regime with turbulent flow and one sub-regime with laminar flow. Rock environment should be then characterised by an existence of crushed water-bearing zones – in this case fault zones of Vajskovská and Suchá valley. Mean degree of vulnerability reaches value of **5.25** (*Tab. 1*). We can assume higher risk of groundwater contamination by surface entry into the rock block and also by significant point source of contamination with direct connection of the karst system to the surface.

The third hydraulic system – inner groundwater circulation inside the hydrogeological structure itself – reaches lower, **2.5** value of vulnerability degree (*Tab. 2*). Generally only a laminar groundwater flow is present in

Number (SHMI)	*Name of spring*	*Site*	*Rock environment*	*Groundwater vulnerability of gauged springs*	*Vulnerability of litological types*	*Final vulnerability of second hydraulic system*
1257	Kings´s Matyas spring	Dolná Lehota	Gutenstein limestones	9.0	5.0	5.25
1311	Uhlište	Dolná Lehota	Gutenstein limestones	5.5		
1312	Vrabec	Dolná Lehota	Choč dolomites	4.3	3.3	
1313	Horný 1, 2, 3	Dolná Lehota	Choč dolomites	4.0		
1314	Horný 4	Dolná Lehota	Conglomerates of Vajsková	5.0	4.1	
1315	Dolný	Dolná Lehota	"Hauptdolomites"	5.5	5.5	

Tab. 1: Groundwater vulnerability of the second hydraulic system of fault zones of Vajskovská valley and Suchá valley.

Number (SHMI)	*Name of spring*	*Site*	*Rock environment*	*Groundwater vulnerability of gauged springs*	*Vulnerability of litological types*	*Final vulnerability of second hydraulic system*
1255	Hámor	Dolná Lehota	Conglomerates of Vajsková	2.7	4.1	2.5
1310	Za továrňou	Dolná Lehota	Choč dolomites	2.5	3.3	
1317	Starý mlyn	Dolná Lehota	Choč dolomites	2.0		

Tab. 2: Groundwater vulnerability of the third hydraulic system – inner groundwater circulation inside the hydrogeological structure.

this hydraulic system, what is typical for rock environment with dense, regular fissure network, with majority of micro-fissures and small fissures. The probability of groundwater contamination is then very small, with the exception of possible entry of contamination from closer vicinity.

CONCLUSIONS

Final groundwater vulnerability map of research area (Fig. 6), showing a spatial distribution of groundwater sensitivity to pollution – groundwater vulnerability – was based on the reclassification of geological map. Individual lithological types were linked to certain vulnerability degree, depending on the mean value defined from the individual springs recession curves characteristics. The large part of area is highly vulnerable, with vulnerability values of more than **4.9** degree of Kulman´s scale (2000) extended by Malík (2005).

This fissure-karst rock environment in the hydrogeological structure on the southern slopes of the Nízke Tatry Mts. between Podbrezová, Krpáčovo, Jasenie and Lopej is widely crushed, with majority of opened, karstic or non karstic fissures and large karst channels. We can assume higher risk of groundwater contamination by surface entry into the rock block here. But in the case of aerial entry of contamination there is still a possibility of its significant retention, absorption and elimination by other processes. Also large part in the centre of structure reaches moderate vulnerability, between **4.0** and **4.9** degree. In this rock environment we can anticipate the existence of open small fissures in combination with simple, partly phreatic conduit system of considerable extent. Contamination by surface entry is lower, but the possibility of contamination by significant point source with direct connection of the karst system to the surface is real. In the case of aerial entry of contamination, there

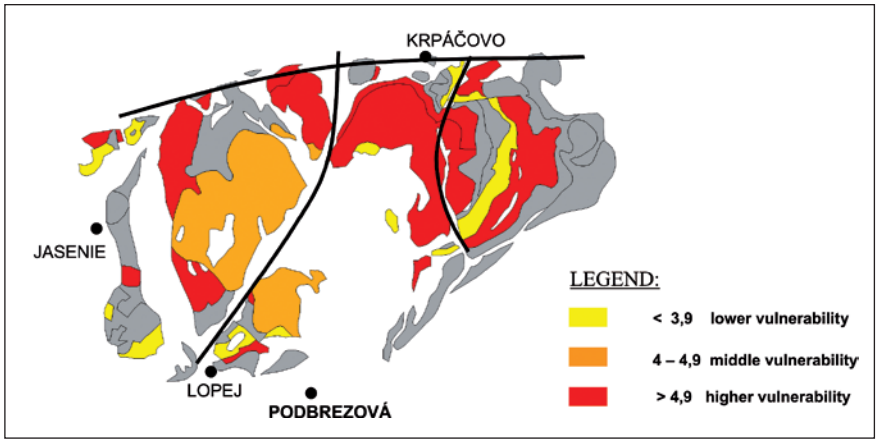

Fig. 6: The outcome map of groundwater vulnerability of research area – hydrogeological structure betwen Podbrezová, Krpáčovo, Jasenie and Lopej, Slovakia.

is a possibility of its significant natural attenuation. Only few small parts of hydrogeological structure represent areas with low risk of groundwater contamination, with value of vulnerability degree smaller than **3.9.** Rock environment represent a dense network of micro-fissures and small fissures, with only limited extent of karst channels. The risk of more extensive groundwater contamination is very low, with the exception of close vicinity to the pollution source

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A STEADY STATE HYDRAULIC MODEL OF A KARST AQUIFER

STACIONARNI HIDRAVLIČNI MODEL KRAŠKEGA VODONOSNIKA

Janez TURK[1]

Abstract UDC 556.34

Janez Turk: A steady state hydraulic model of a karst aquifer

It is known, that 90 % or even more of underground water flows through large conduits. Restrictions and siphons represent only small percentage of karstic aquifer. But because of them, conduits, which transmit water, are only partly accessible. Difficult access is a reason why many water transmissions have not been explored yet. Because of this, geometry and length of all underground conduits is not known, it can be only predicted. In such a case processes of water flow in karstic conditions are more easily predictable by modeling. Basic physical models are usually used. They are based on the conduit permeability of karst water. We assume conduits with different dimensions, smaller usually presenting areas of full pipe flow (under pressure) and larger open channel flow. We were interested in the hydraulic conditions, when does the change from open channel to full pipe flow occur and when does underground flow from main conduit divide into two neighbouring conduits. The response of a karst aquifer to a flood pulse was not studied in our model, but we observed its behaviour during a constant increase of recharge into the karstic underground.

Key words: karst modeling, underground karst system, open channel flow, full pipe flow.

Izvleček UDK 556.34

Janez Turk: Stacionarni hidravlični model kraškega vodonosnika

Dejstvo, da se kar 90 % ali celo več podzemne kraške vode pretaka po velikih kraških kanalih je splošno znano. Zožitve v obliki sifonov predstavljajo le manjši delež kraških prevodnikov. Vendar so zaradi njihovega pojavljanja kraški kanali, ki prevajajo vodo le deloma dostopni. Zaradi težavnega prehoda prek sifonov veliko kraških kanalov še ni bilo raziskanih. Geometrija in dolžina vseh kraških prevodnikov torej ni znana, lahko jo le predvidevamo. V takšnem primeru je procese pretakanja podzemne kraške vode najenostavneje ugotavljati z modeliranjem. Večinoma se uporablja enostavne fizikalne modele, ki temeljijo na kanalski prevodnosti kraške vode. Predpostavimo kanale različnih dimenzij, vmesni manjši običajno predstavljajo območja toka pod tlakom, večji kanali pa se obnašajo kot rezervoarji. V našem modelu smo se osredotočili na robne pogoje, ob katerih pride do spremembe toka s prosto gladino v tok pod tlakom in pogoje ob katerih se podzemni tok razdeli med dva sosednja kanala. V obravnavanem modelu nismo ugotavljali odziva kraškega vodonosnika na nek poplavni sunek, pač pa njegovo obnašanje ob konstantnem povečevanju dotoka v kraško podzemlje.

Ključne besede: kraško modeliranje, podzemni kraški sistem, tok s prosto gladino, tok pod tlakom.

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INTRODUCTION

Characterisation of karst aquifer is a difficult task, because the position and geometry of conduit network which transmits most of groundwater is not known. If the geometry is at least approximately known or can be predicted and the recharge into the underground system can be measured (or estimated) we can make a simplified model.

Models can be imaginary or a simplification of realistic conditions in the karst underground. We should be aware that all estimations can be very approximate and results are not always reliable. The easiest way to reconstruct underground karst water flow is to use models. There are two major approaches:

- Global methods are based on the analysis of spring discharge and precipitation time series. These data reflect hydraulic characteristics of underground system. But the spatial heterogeneity and structure of karst underground is neglected, so only qualitative interpretation is possible (Sauter 2005).

- Distribute methods incorporate two concepts. First is a discrete concept, which describes flow within networks of fractures or conduit (Sauter 2005). This method assumes different structures of karst aquifer and a simplified geometry of conduits. It can be used to assume the amount of underground water flow or aquifer's response to a certain storm event (Halihan et al., 1998). The discrete concept was used in our model. Water flow in our model is treated as one-dimensional and conduits have different permeability.

Second is a continuum concept and it treats heterogeneities in terms of effective model parameters and their spatial distribution. A hybrid model is a combination of both concepts (Sauter 2005).

Before starting any modeling some important features of karst aquifer should be considered: recharge, discharge, geometry of the system, permeability, friction factor and boundary conditions (White 2003 & Springer 2003 & Kiraly 2002).

- Recharge can be allogenic from the sinking streams, autogenic through the epikarst or combination of both (Ford & Williams 1989).

- Discharge can be measured before a river sinks underground. We should be aware of possible water losses into larger or smaller fractures inside the cave system, recharges as underground tributaries and autogenic infiltration (Springer 2003).

- Geometry of the model is simplified. Karst water flows through a system of conduits and fractures which have different diameters. Conduit shapes are very irregular and it is almost impossible to predict them. Constrictions between conduits may cause back flooding. Conduits may divide or combine into more or one.

- Permeability is linked with the porosity. In general we distinguish inter-granular, fracture and conduit permeability. More than 90 % of underground karst waters flow through large conduits (Bonacci 1987).

- Friction happens within water flow and at the contact of water and bedrock. The higher the friction, the lower are flow velocities. Cave walls have a friction factor between 0.028 and 0.13, according to measurements in many caves (Springer 2003). It is linked also with lithology. Inside one cave system, the friction factor is very variable parameter.

- Boundary conditions which affect discharge flow regime in karst underground are hydraulic head and recharge (Kiraly 2002).

A brief review of the literature indicates, that most models were based on an assumption of water flow through conduits with different dimensions (system consisting of large conduits and restrictions between them). For example, Halihan and Wicks (1998) interpret large conduits as reservoirs with free water surface. Permeability of the whole system is determined by the smallest constriction, through which water is transmitted under pressure (as a full pipe flow). The purpose of such models is to interpret flood response of karst aquifer.

Campbell et al. (2002) used a computer program Storm water management model (EPA, SWMM) to calculate energy losses in the karst underground. They considered both full pipe flow and open channel flow.

The aim of this paper is to demonstrate different possible flow scenarios within karst aquifer based on the simple model of discrete conduits and reservoirs. The model can be divided into two sub-domains. Flow from lake (A) to the underground chamber (B) and to the wire (see chapter "model description and data") can be considered as an input to the lower conduit system. Second sub-domain represents flow from the wire to the conduit system 2-3-4 and 5-6 (Fig. 1), where we assume three different flow scenarios:

- open channel flow in primary conduits
- full pipe flow in primary conduits
- full pipe flow in all conduits

The geometry of the system is assumed to be constant, but hydraulic parameters are variable. Relations between water levels (of the lake and underground "reservoirs") and discharge were observed. In three different scenarios, attention will be given to the behaviour of underground water flow through large conduits with different diameters at different hydraulic conditions (hydraulic gradient and discharge)

MODEL DESCRIPTION AND DATA

The model represents a system of underground conduits between higher located lake and karst spring (Fig.1). Underground conduits are supplied by the lake water. The sinkhole is active all the time in our model, because lake has a positive water balance.

Lake water, sinking into the underground flows first through a conduit until it reaches an underground chamber. Water balance of the lake enables full pipe flow through the first conduit.

Water stagnates in the underground chamber. Some rocky barrier, such as a rockfall, causes water stagnation. As a result, an underground karst lake forms. The barrier behaves like a weir. It is long enough, that water cannot reach the chamber's ceiling even during the highest discharges. The water has free surface in the underground chamber during any discharge conditions.

The water spills over the barrier (weir) into the next conduit. It splits into two parts of which the lower conduit is the main and is active all the time. The upper conduit is secondary and it is active only during episodic water conditions. Both conduits join together before the spring. The water emerges at altitude, which is 50 m lower than the bottom of the lake.

The hydraulic model has geometry precisely as possible determined. All parameters and their typical values are given in Tab 1. Geometrical symbols are also shown in Fig. 1, where L is length and Φ is a diameter of conduit.

The model tried to represent useful usage of hydraulic equations in karst underground. Our model is a fiction, but anyway very similar features between two karstic poljes are possible. There are a few connected poljes in Dinaric karst. The most famous Slovenian seasonal lake is in Cerkniško polje. There are a lot of swallow holes at the bottom of the Cerknica lake and water emerges in many springs few tenth kilometers away, at the contact of carbonate Jurassic rocks with Quaternary sediments which fill the tectonic basin of Ljubljana moor.

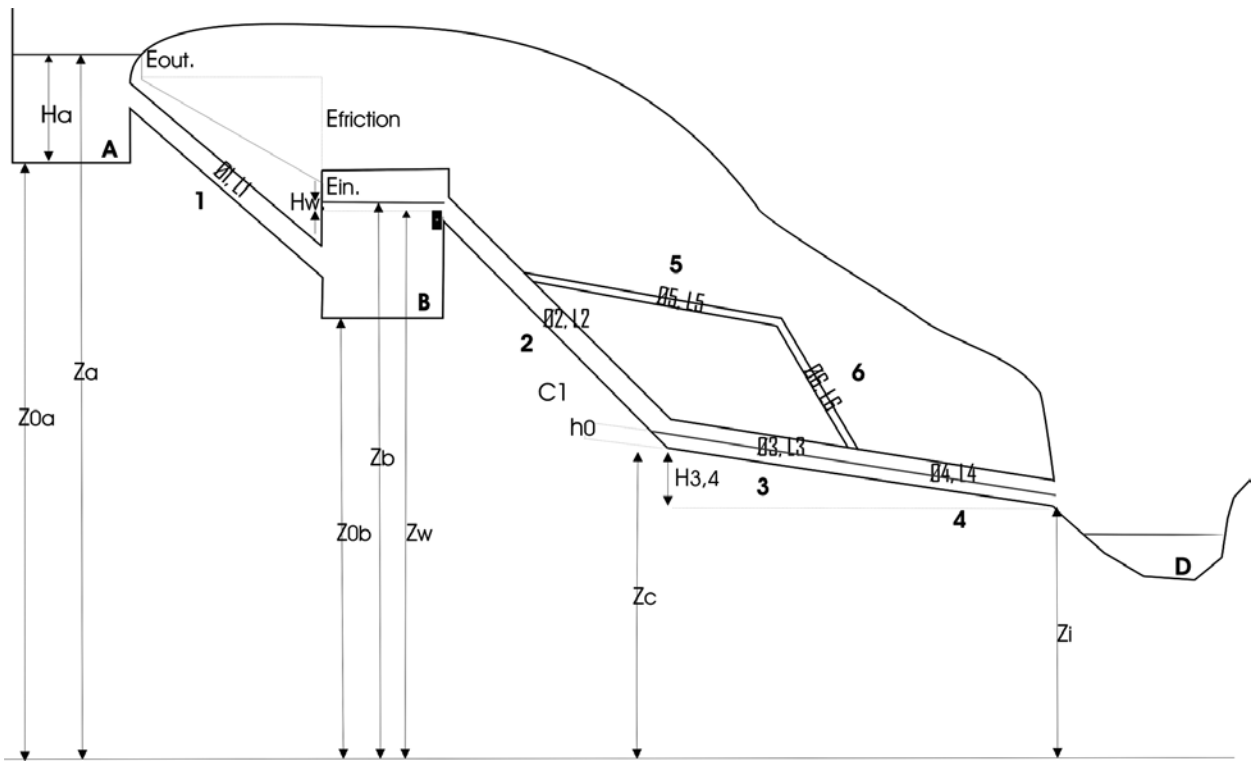

Fig. 1: Shematic review of underground system.

GEOMETRICAL DATA	
$Z_{a-min.}$ [m]	102
Z_{0a} [m]	60
H_a [m]	42
Z_b [m]	Z_w+H_{weir}
Z_{0b} [m]	30
Z_w [m]	52
Z_c [m]	12
Z_{split} [m]	42
ΔH_{split} [m]	30
$\Delta H_{3,4}$ [m]	2
ΔH_{split} [m]	30
Φ_1 [m]	3
L_1 [m]	200
Φ_2 [m]	5
L_2 [m]	200
$L2_{split}$ [m]	150
Φ_3 [m]	5
L_3 [m]	150
Φ_4 [m]	5
L_4 [m]	150
Φ_5 [m]	3
L_5 [m]	150
Φ_6 [m]	3
L_6 [m]	150
trapezium	
h [m]	5
D [m]	2
B [m]	2
m	0.4

FRICTION FACTORS	
Ng	0.03
Ng trapezium	0.11
λ_1 [s/m⅔]	2.6
λ_2 [s/m⅔]	2.2
λ_3 [s/m⅔]	2.2
λ_4 [s/m⅔]	2.2
λ_5 [s/m⅔]	2.6
λ_6 [s/m⅔]	2.6
COEFFICIENTS OF LOSSES	
$\xi_{outflow\ A-1}$	0.2
$\xi_{outflow\ 4-D}$	1
$\xi_{knee\ 2-3}$	0.1
$\xi_{knee\ 5-6}$	0.15
$\xi_{inflow\ 6-4}$	0.15
WEIR	
μ	0.79
b [m]	10

Tab. 1

SCENARIOS AND EQUATIONS

First, some estimations should be done. Conduit roughness coefficient was estimated as Ng = 0.03 s/m⅓ (Steinman 1999 & Rossman 2004). We assume limestone walls with a relative high roughness.

Friction factor (λ) depends on conduit diameter and roughness coefficient (Ng). We use connection between friction factor (λ) (after Darcy-Weissbach) and Manning's roughness coefficient (Ng):

$$\lambda = 124,6 * \frac{Ng}{\phi^{1/3}} \qquad (1.)$$

Values of friction factors are given in Tab. 1.

FLOW FROM THE LAKE TO THE WEIR

Domain can be considered as a system of two connected reservoirs. Flow between the reservoirs is full pipe, because water level of the lake is all the time above the sinkhole according to our hypothesis (Fig. 1).

In this scenario, water level of the lake and height of water spilling over the weir at some variable discharges were calculated. Flow between two "reservoirs" and spilling over the weir are independent on further hydraulic conditions and type of flow in conduits (2-3-4) or (5-6).

First some initial discharge must be chosen or calculated, which will be arbitrary increased. We will then calculate water height at weir (H_{weir}) and losses in the conduit. Finally water level of the lake (Za) will be calculated.

Relation between discharge (Q) and flow velocity (v) is described by following equation:

$$Q = A * v = \pi * (\frac{\phi}{2})^2 * v \qquad (2.)$$

A – cross section area of conduit filled with water [m²]
Φ – pipe diameter [m]

The system of flow between lake (A) into underground chamber (B) through conduit (1) is expressed by Bernoulli's equation:

$$\frac{p_1}{\rho g} + h_1 + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + h_2 + \frac{v_2^2}{2g} + \sum(\Delta E) \qquad (3.)$$

p – hydrostatic pressure [Pa=N/m²]
ρ – density [kg/m³]
g – gravitational acceleration = 9,8 m/s²
h – height above arbitrary comparative surface [m]
Σ(ΔE) – sum of all energy losses.

Hydrostatic pressure exists only in reservoirs completely filled with water, otherwise $\frac{p}{\rho g}$=0.

Therefore the difference between the potentials in the lake and reservoir is equal to the energy losses in the conduit (Fig. 1):

$$Z_a = Z_b + \Delta E \qquad (3.1)$$

where:

$$\Delta E = \Delta E_{inf\,low} + \Delta E_{friction,l} + \Delta E_{outflow}$$

ΔE is energetic loss. We distinguish friction and local losses (local losses occur at every change of streamline: for example at stream expansion and narrowing, at outflow from a conduit into a larger underground chamber and the opposite, at bends etc.).

Friction losses in the circular conduit are calculated by Darcy-Weissbach equation:

$$\Delta E_{friction} = \lambda \frac{L}{\Phi} * \frac{v^2}{2g}$$

L – pipe length [m]
Φ – pipe diameter [m]
Hydraulic diameter for circular pipe is considered as

$$R = \frac{A}{P} = \frac{\Phi}{4}$$

P – perimeter of cross section [m]

Local losses (inflow and outflow) must be added to get total energy losses. These are given by following equation:

$$\Delta E_{local} = \xi_{local} * \frac{v^2}{2g}$$

ξ – coefficient of local loss

The Bernoulli's equation (3) then becomes

$$Z_a = Z_b + \frac{v^2}{2g} * \left(\xi_{inflow} + \lambda \frac{L_l}{\phi_l} + \xi_{outlow} \right) \qquad (3.2)$$

where $\xi_{outflow} = 1$ (Steinman 1999)

The level Z_b in the reservoir (B) equals to $Z_w + H_{weir}$, where the H_{weir} is the height of the water at the weir *(Fig. 1)*. To get some basic, initial discharge, we first assume that water level in reservoir (B) increases only until it reaches the top of the weir, therefore $H_{weir}=0$ and $Z_b=Z_w$. After this presumption, we can use equation (3.2) to calculate velocity (v) and then we use equation (2) to calculate initial discharge (Q). After consideration that $Z_b=Z_w$, minimum discharge can be calculated, at some minimum Z_a. All following calculations are based on that minimum discharge.

Q_{min}=16,77 m³/s (initial discharge), according to our calculations (respectively rounded up to 16,8 m³/s). Arbitrary values are added up to Q_{min}. So the discharge is being increased gradually which is a consequence of rising water level of the lake. Discharge through karst conduit (1) increases proportionally with flow velocity (v) (equation 2) along the conduit (l). Consequently water level in the underground chamber (B) is changing. The higher the discharge, the higher is the water level spilling over the weir (equation 4.1). The weir is a barrier (rockfall). Water spills over the barrier into next karst conduit.

Discharge over barrier (weir) is calculated by the equation for a perfect weir. Perfect weir (Fig. 2) can not be flooded by downstream water.

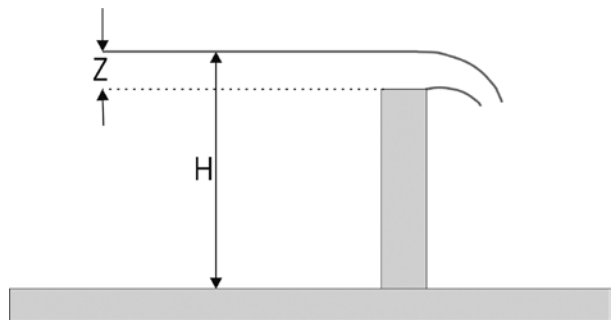

Fig. 2: Sketch of perfect weir.

$$Q = \frac{2}{3} * \mu * b * \sqrt{2g} * H_{weir}^{2/3} \qquad (4.)$$

Where

μ – weir coefficient (it can be read from tables in the literature)
b – weir width [m]
H_{weir} – height of spilling water above the weir [m]

Weir coefficient μ was estimated to 0.79 (Steinman 1999)

From equation (4.) H_{weir} can be expressed:

$$H_{weir} = \left(\frac{Q}{\frac{2}{3} * \mu * b * \sqrt{2g}} \right)^{3/2} \qquad (4.1)$$

Water level in the underground chamber (value Z_b) is:

$$Z_b = Z_w + H_{weir} \quad (5)$$

Calculated value H_{weir} is put in equation (5) to get level of water in the underground chamber (B) (respectively value Z_b) at different discharges. Value Z_b is put into equation (3.2) to get water level of the lake (Z_a) at different hydraulic conditions. Water level of the lake is the parameter, which has the main influence on discharge variations within the karst underground.

The function of water levels is shown in Fig. 3.

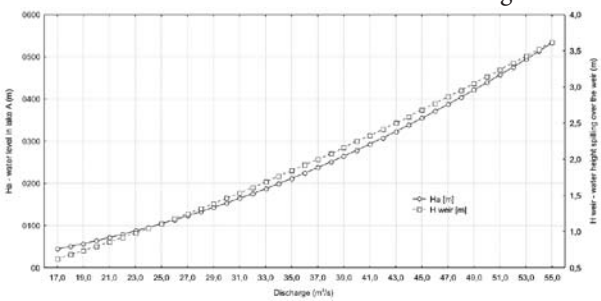

Fig. 3: Relation between water levels (m) and discharge (m3/s).

SCENARIO 1: OPEN CHANNEL FLOW THROUGH CONDUITS (2-3-4) AFTER SPILLING OVER THE WEIR

In scenario 1, special interest will be given in transition from open channel flow to full pipe flow and water level heights (h_0) in conduits 3 and 4 (Fig. 1). But to consider open channel flow, one condition has to be satisfied: $5 > h_0 \geq 0$ m (because height of the conduit is 5 m).

For the simplicity of calculations we assume trapezoidal cross section of conduits 3 and 4 only in scenario 1. All conduits in all other examples have circular cross sections. Furthermore, also roughness coefficient in trapezoidal conduits is changed to Ng=0.11 in scenario 1.

Discharge for open channel flow is calculated after Manning:

$$Q = \frac{\sqrt{I}}{Ng} * \frac{A^{5/3}}{P^{2/3}} \quad (5.)$$

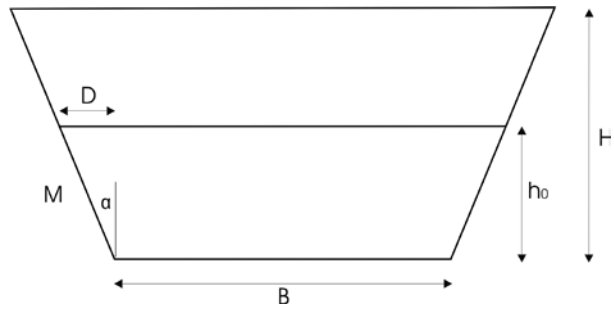

Fig. 4: Cross section of trapezoidal conduit.

Where A and P are flow cross section and perimeter of flow. They are given by:

$$A = bh_0 + mh_0^2 \quad (6.)$$

$$P = b + 2s = \frac{2h_0}{\sin\alpha} = b + 2h_0\sqrt{1+m^2} \quad (7.)$$

Where

$$m = tg\alpha = \frac{D}{h}$$ see Fig. 4

Values D, B and h are given in tab. 1

And hydraulic gradient I:

$$I = \frac{\Delta H_{3,4}}{L_{3-4}}$$

Applying equations (6.), (7.) into equation (5.) we get:

$$Q = \frac{\sqrt{I}}{Ng} * \frac{(bh_0 + mh_0^2)^{5/3}}{(b + 2h_0\sqrt{1+m^2})^{2/3}} \quad (8.)$$

Open channel flow through conduits 3 and 4 is possible until recharge 20 m^3/s, according to our calculations. Both conduits fill up with water during higher discharges and full pipe flow occurs. It is described in scenario 2.

Error as a consequence of simplifying of cross section geometry can be determined. Cross section of trapezoidal conduit (equation 6) should be as possible similar to cross section of circular conduit with diameter 5 m *(Fig. 5)*. The ratio between cross sections areas is trapezium : circle = 20 m^2 : 19,6 m^2.

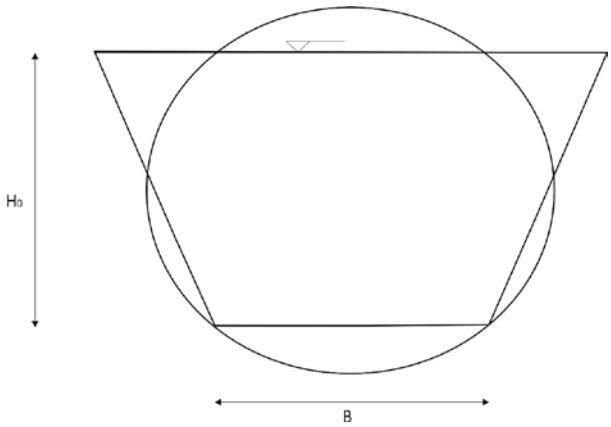

Fig. 5: Trapezoidal and circular cross sections should be similar as possible.

SCENARIO 2: FULL PIPE FLOW THROUGH PRIMARY CONDUITS ONLY

It is assumed that conduit 2 acts as a reservoir and the water level in it is restricted 30 m>h_c>ΔΦ3, otherwise water would start to flow through conduit 5 and 6. Secondary conduits split from the primary at height h_{split} = hc = 30 m (Fig. 6).

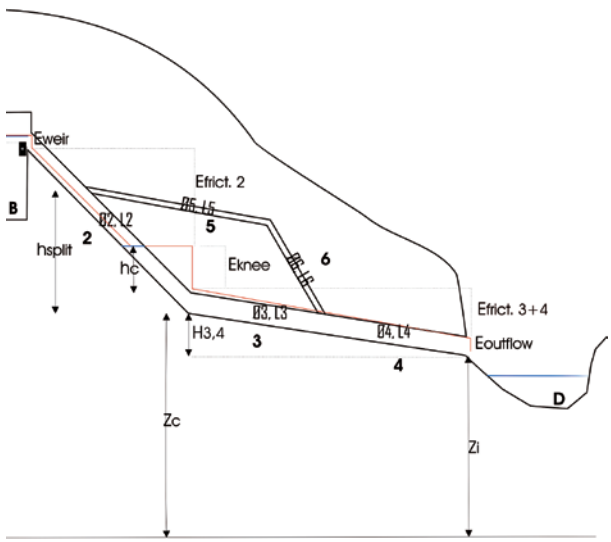

Fig. 6: Shematic review of scenario 2.

We would like to find out the boundary discharge, which causes flow trough secondary conduit (5-6). Also correlation between discharge and water level in conduit h_c (considering the condition 30 m >h_c > 5 m) can be determined (Fig. 7). First we calculate velocities for selected discharges (using equation (2.): $v = \frac{Q}{0,25*\pi*(\Phi)^2}$)

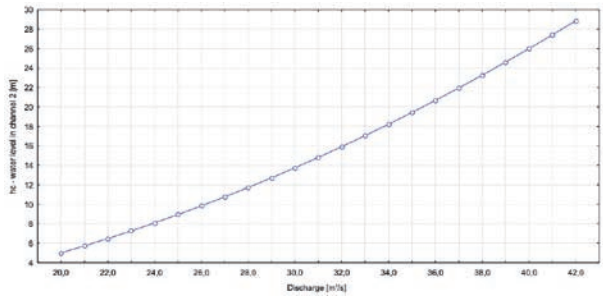

Fig. 7: Relation between water level in conduit 2 and discharge.

and then water level in conduit 2 (value hc) using equation (9.1).

$$h_c + \Delta H_{3,4} = \Delta E_{knee} + \Delta E_{friction,3-4} + \Delta E_{outflow} \quad (9)$$

$$h_c = \frac{v^2}{2g}(\xi_{knee} + \lambda_{3-4}\frac{L_{3-4}}{\phi_{3,4}} + \xi_{outflow}) - \Delta H_{3,4} \quad (9.1)$$

Full pipe flow through conduits 3 and 4 is possible for discharges above 20 m³/s. Until discharge does not exceed 43 m³/s, water does not flow through secondary conduits 5 and 6.

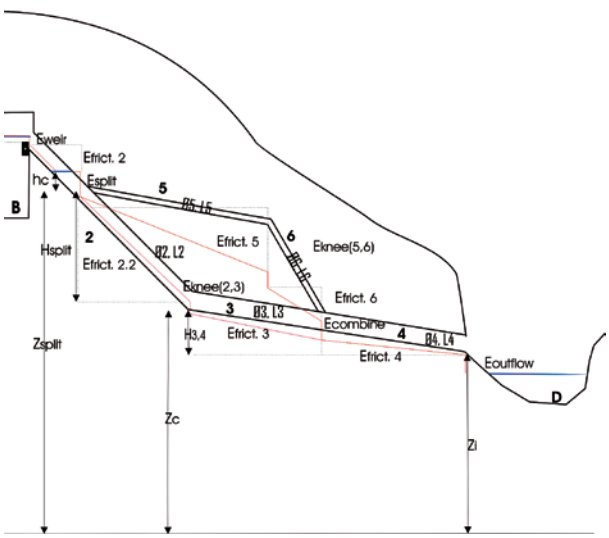

Fig. 8: Shematic review of scenario 3.

SCENARIO 3: FULL PIPE FLOW THROUGH PRIMARY AND SECONDARY CONDUITS

The water starts to flow through secondary conduits at discharge 43 m^3/s (accurately 42.9 m^3/s), as was determined in scenario 2. Start of secondary flow should occur at higher discharge in scenario 3, but it does not happen. Water starts to flow through secondary conduits at discharge 41.5 m^3/s according to calculations in scenario 3. Reason is in some simplifications, especially in neglecting friction losses within conduit 2 in scenario 2. Friction losses are considered in scenario 3, therefore boundary discharges between two scenarios can not be compared.

Because scenarios 2 and 3 are incompatible, scenario 3 will be used only to find out relation between flow rates in both primary and secondary branches (Fig. 9). It is assumed that the total flow rate exceeds 41.5 m^3/s and the flow is full pipe in both branches.

Discharges at the spring are considered to be known. Velocities using equation (12.) are calculated first. Velocity v_{2-3} is in relation with velocity v_{5-6} (equation 11.3). When velocities are known, equation (2) is used to calculate discharges Q_{2-3} and Q_{5-6}. Their sum should be equal to the common Q (equation 10).

Flow splits to two components

$$Q = Q_{2-3} + Q_{5-6} \tag{10}$$

Energy drop along both branches (2-3 and 5-6) is equal (Fig. 8)

$$\Delta E_{2-3} = \Delta E_{5-6} \tag{11}$$

$$\Delta E_{friction,2.2} + \Delta E_{knee(2,3)} + \Delta E_{friction,3} = \Delta E_{friction,5} + \Delta E_{knee(5,6)} + \Delta E_{friction,6} + \Delta E_{combine} \tag{11.1}$$

$\Delta E_{combine}$ was neglected. Applying equations for friction and local losses we get:

$$\frac{v_{2-3}^2}{2g} * \left(\lambda_{2-3} * \frac{L_2^{split}}{\phi_2} + \xi_{knee(2,3)} + \lambda_{3-4} * \frac{L_3}{\phi_3}\right) = \frac{v_{5-6}^2}{2g} * \left(\lambda_{5-6} * \frac{L_5}{\phi_5} + \xi_{knee(5,6)} + \lambda_{5-6} * \frac{L_6}{\phi_6}\right) \tag{11.2}$$

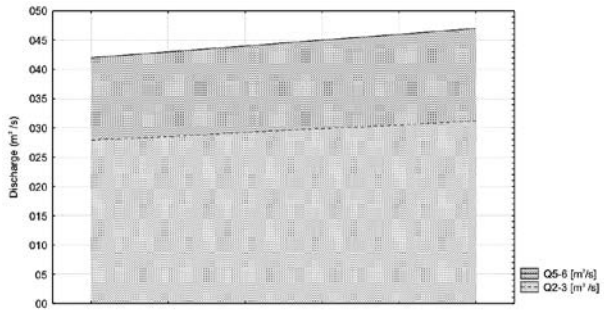

Fig. 9: Comparison of two discharge components through conduits 5-6 and 2-3. Both components present common discharge.

The ratio between velocities v_{2-3} and v_{5-6} is written as:

$$v_{2-3} = \sqrt{\frac{\lambda_{2-3} * \frac{L_2^{split}}{\phi_2} + \xi_{knee(2,3)} + \lambda_{3-4} * \frac{L_3}{\phi_3} + }{\lambda_{5-6} * \frac{L_5}{\phi_5} + \xi_{knee(5,6)} + \lambda_{5-6} * \frac{L_6}{\phi_6}}} * v_{5-6} = n * v_{5-6} \tag{11.3}$$

Where symbol n presents calculated value under the square root.

Employing equation (11.3) and relation $Q = \pi * (\frac{\phi}{2})^2 * v$ in equation (10.) we get

$$Q = \pi * (\frac{\phi_{2-3}}{2})^2 v_{2-3} + \pi * (\frac{\phi_{5-6}}{2})^2 * \left(n * v_{2-3}\right) \tag{12.}$$

After calculating velocities, equation (12.) can be used to determine discharges Q_{2-3} and Q_{5-6}.

Proportion of two discharge components is shown in Fig. 9.

CONCLUSSION

Geometry of the model had an important role on relation between water level in reservoirs (lake, underground chamber) and discharge through system. Our calculations showed, that water level should rise for about 280 m to cause flow through secondary conduits 5 and 6, which is also a consequence of geometry. Unreliable water level indicates that chosen geometry was not optimal.

Scenarios 1 and 2 are used to represent equations for open channel flow and full pipe flow within conduit. When discharge exceeds 20 m^3/s, open channel flow is not possible anymore in conduits 3 and 4. A lot of simplifications were used especially in scenario 1, so a difference between boundary discharges at the transition from open channel flow to full pipe flow could be big. To make calculations easier, we assumed a conduit with trapezoidal cross section for open channel flow only (scenario 1), otherwise conduits cross sections are circular. The difference between the two cross sections with different shapes was only two per cents. Problem of misfit results would be more a consequence of a hydraulic jump. It was solved by changing roughness coefficient in trapezoidal conduit (3-4) (scenario 1). Otherwise roughness coefficients were constant in all conduits for all scenarios.

Scenario 3 was used to find out relations between discharges through primary and secondary conduits. Proportion between two discharges is almost 2:1. Discharge, which causes water flow through secondary conduits should exceed 43 m^3/s or 41.5 m^3/s, depending on neglecting or considering friction losses in conduit 2.

As can be imagined, model calculations are far from optimal, but they may offer some considerations for modeling karst aquifers.

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PATTERNS AND PROCESSES OF GROUNDWATER INVASION BY COPEPODS IN THE INTERIOR LOW PLATEAUS OF THE UNITED STATES

VZORCI IN PROCESI NASELJEVANJA CEPONOŽCEV V PODZEMELJSKE VODE NA PLANOTI INTERIOR LOW PLATEAUS V ZDRUŽENIH DRŽAVAH

Julian J. LEWIS[1] & Janet W. REID[2]

Abstract UDC 574.9:595.34 (7)

Julian J. Lewis & Janet W. Reid: Patterns and Processes of Groundwater Invasion by Copepods in the Interior Low Plateaus of the United States

The copepod crustacean fauna collected from subterranean habitats, including caves, wells, and the hyporheos of streams in and near the Interior Low Plateaus of the United States is dominated by Cyclopoida, with 39 species, followed by Harpacticoida with 9, and Calanoida with 2. Nearly all of the harpacticoid and calanoid species are widespread, primarily surface-dwelling generalists. Fourteen of the cyclopoids, members of the genera *Diacyclops, Itocyclops, Megacyclops,* and *Rheocyclops*, are apparently obligate stygobionts or hyporheic. Several of the species that are more strongly modified for subterranean existence occur only in the more southern, unglaciated areas. Our sampling data support the hypothesis that the more specialized, groundwater-interstitial species have been unable to disperse into previously glaciated regions; whereas some, less-specialized species may have invaded groundwaters from surface habitats as the glaciers receded.

Key words: Copepoda, Crustacea, biogeography, glaciation, North America.

Izvleček UDK 574.9:595.34 (7)

Julian J. Lewis & Janet W. Reid: Vzorci in procesi naseljevanja ceponožcev v podzemeljske vode na planoti Interior Low Plateaus v Združenih državah

Med ceponožnimi raki, vzorčevanimi v podzemeljskih habitatih, v jamah, vrtinah in rečnem hiporejiku blizu ter na sami planoti Interior Low Plateaus (ZDA), prevladujejo ciklopoidi z 39 vrstami, sledijo jim harpaktikoidi z devetimi vrstami in kalanoidi z dvema vrstama. Skoraj vse identificirane harpaktikoidne in kalanoidne vrste so splošno razširjene, površinski generalisti. Štirinajst ciklopoidnih vrst, predstavnikov rodov *Diacyclops*, *Itocyclops*, *Megacyclops* in *Rheocyclops*, je stigobiontov ali prebivalcev hiporejika. Vrste, ki imajo močneje izražene prilagoditve na podzemeljsko življenje, najdemo v južnih predelih, ki v času ledenih dob niso bili pokriti z ledenim pokrovom. Rezultati vzorčenja podpirajo hipotezo, da tiste vrste, ki so bolj specializirane na podzemeljske-intersticialne pogoje niso bile sposobne razširjenja v predhodno poledenele predele; medtem ko so nekatere, manj specializirane vrste ob umikanju ledenikov uspele prodreti iz površinskih v podzemeljske vode.

Ključne besede: Copepoda, Crustacea, biogeografija, poledenitev, Severna Amerika.

INTRODUCTION

We review published information and present new geographical records for the copepod crustaceans collected from subterranean habitats in and near the Interior Low Plateaus (ILP) physiographic province of the United States. Fenneman (1938) described the ILP as an area of relative lowlands between the Appalachians to the east and the Ozark Plateaus to the west. The ILP stretches from northern Alabama, northward through Tennessee and Kentucky into southern Indiana and Illinois. Much of this area is karst topography and contains thousands

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of known caves. The northern boundary of the ILP is the terminus of the Illinoian glaciation. Herein we trace the present-day distribution of the copepod species in this region, and attempt to infer the historical patterns and routes of their re-entry into previously glaciated areas.

The Interior Low Plateau region has been the focus of many earlier studies relating to the fauna of caves and karst, because of the notoriety of some local sites, especially in the central Kentucky karst, including what is now Mammoth Cave National Park. In 1928, C. Bolívar and René Jeannel made collections of copepods from numerous caves in the eastern United States, resulting in the first descriptions (Chappuis 1929, 1931) of subterranean copepod taxa from this country: *Megacyclops donnaldsoni* (Donnaldson Cave, Lawrence County, Indiana), *Diacyclops jeanneli* (Marengo Cave, Crawford County, Indiana), and *Bryocamptus morrisoni* (Horse Cave, Hart County, Kentucky; and Donnaldson Cave). *Cyclops clandestinus* (renamed *Diacyclops yeatmani* by Reid, 1988) was described from Big Mouth Cave, Grundy County, Tennessee and a drain tile in Vermilion County, Illinois by Yeatman (1964). Barr (1967) summarized collections of 17 taxa reported from Mammoth Cave and other caves in the central Kentucky karst by his own field work, as well as that of Kofoid (1899) and Chappuis (1931).

Lewis began sampling cave faunas in the eastern United States in the 1970s, but only started focusing attention on the micro-crustacean fauna in the 1990s (Lewis, and Lewis et al. 1998-2006). The initial impetus for these collections was the desire to rediscover *Diacyclops jeanneli* in Marengo Cave and the surrounding area during a survey conducted for The Nature Conservancy in Indiana. The results from this sampling made it clear that a significant assemblage of subterranean microcrustaceans was present in the groundwaters of the midwestern United States. Presented herein are the results of Lewis' approximately 15 years of sampling. Newly described copepod taxa resulting from these collections are *Rheocyclops indiana* (Reid et al. 1999), *Diacyclops salisae, D. lewisi, D. indianensis* and *D. conversus* (Reid 2004), and a new species of *Itocyclops* (Reid in review).

SAMPLING METHODS

A variety of means were used to collect copepods from different windows into the groundwater. Plankton drift samples were collected by hanging a plankton net over the orifice of a spring, in a flowing cave stream, or at the mouth of a drain tile. In deeper streams, rimstone pools, or drip pools in caves, the net was drawn through the water. In shallow drip pools, fed by the epikarst, water was dipped with a cup and strained through the plankton net. In cave streams with sufficiently deep gravel, the Karaman-Chappuis technique was used to gather fauna living in the interstices. In wells, copepods and other fauna came readily to jars equipped with perforated lids and baited with a single, uncooked dead shrimp; these were left overnight and then retrieved. Longer trapping intervals appeared to result in fouling of the water and decrease in the fauna that was captured. Finally, a Bou-Rouch pumpwell was used to sample hyporheic interstices of the Blue River in southern Indiana.

All samples were transported alive to the laboratory for visual inspection. The copepods and other fauna were much easier to detect alive than preserved. The animals were removed from the sample with an eye dropper, and then preserved in 70% ethanol. Voucher specimens were deposited in the collections of the National Museum of Natural History (Smithsonian Institution), or the Virginia Museum of Natural History.

PATTERNS OF DISTRIBUTION AND HABITAT

Like any other puzzle, a modicum of the pieces have to be gathered and arranged before even a hint of the overall picture begins to emerge. Enough sampling from caves and other windows into groundwater in the Interior Low Plateaus of the east-central United States has now been conducted to permit a few observations about the patterns of distribution, as well as to infer the processes by which copepods have invaded this realm.

One of the ecological fortes of cyclopoid copepods of the genus *Diacyclops* is their use of groundwater habitats, and it appears that some species are indeed stygobionts. The best-known of these in the United States is *Diacyclops jeanneli*. For many decades after its discovery in 1928, this species remained obscure, with even its microhabitat in Marengo Cave uncertain. Using shrimp-baited jar traps, Lewis (1996) found *D. jeanneli* in a well, not

associated with caves or karst, on the edge of the Knobstone Escarpment, in Floyd County, Indiana. This well had been hand-dug many decades earlier, penetrating alluvium and then the top of the New Albany Shale to a total depth of 21 feet (6.4 m) below the surface. Also found in the well was the phreatobitic isopod *Caecidotea teresae,* previously known from a series of drain tiles across the street on the Indiana University Southeast campus in New Albany, associated with an undescribed groundwater amphipod *Stygobromus* sp. (Lewis 1982).

At the time that *D. jeanneli* was first collected from Marengo Cave, a relatively small amount of passage had been explored, and none of the known passages contained a significant stream. Since that time, not only one, but two, cave "rivers" have been connected by explorers to the historic section of Marengo Cave. Lewis (1998) took plankton drift samples in these streams, but did not find *D. jeanneli.* Further sampling revealed that these copepods are fairly common in drip pools in the upper level of the cave, even in shallow pools on the concrete trails used by tourists visiting the cave. The area of the cave where *D. jeanneli* was found is highly decorated with stalactites, stalagmites, and rimstone pools. In contrast to the lower-level cave rivers, all of the water in this part of the cave is epikarstic in origin.

Subsequently, *D. jeanneli* was found in five other southern Indiana caves, in pools fed by ceiling drips. In several instances, the stygobiont ostracod *Pseudocandona jeanneli* or a related, undescribed species of *Pseudocandona* were taken from the same samples. Most recently, *D. jeanneli* has been taken from a seep emerging from alluvium in Clark County, Indiana. It appears that *D. jeanneli* is an inhabitant of groundwater interstices, whether in a cave or not. The cave records may well be incidental findings, where the copepods have fallen in drip water from the preferred epikarst habitat. Clearly, this species is at home in non-karst groundwater interstices as well. Based on the collection of fresh material as noted, Reid (2004) redescribed the species and summarized the localities from which it is now known.

In contrast, present data suggest that *Megacyclops donnaldsoni* is a strict cavernicole. Now known from sporadically located collections in Indiana, Kentucky, and Tennessee, all records are from caves, and all but one from a cave river. Reid (unpublished data) identified a single female ascribable to *M. donnaldsoni,* collected from a stream in Cemetery Pit Cave in Dade County in northwest Georgia, January 2001, by J. Jensen and W. Reeves (specimen in VMNH). The single non-stream habitat was a deep rimstone pool, probably near local base-level, in Dry Cave, Grundy County, Tennessee. Bunting (1973) did not mention the subhabitat of his record from a cave in Tennessee.

Diacyclops yeatmani has now been recorded from the hyporheos of the Blue River in southern Indiana, a drain tile in glaciated Illinois, and three caves in Tennessee. This is remarkable because the species is distributed both south of the Illinoian glacial maximum, and a significant distance north of it, in the till plains of Illinois. A somewhat similar distribution pattern is known for *D. indianensis,* which is recorded from the type-locality in a cave in glaciated southeastern Indiana, and from seven caves in Tennessee. In Indiana *D. indianensis* occurs in a cave about 20 km outside the Illinoian glacial boundary region, whereas *D. yeatmani* occurs perhaps 80-100 km inside this boundary.

Several other species of *Diacyclops* are presently known from one or two sites in southern Indiana: *D. lewisi, D. salisae, D. conversus.* All display some degree of morphological adaptation to the groundwater environment, and are known only from groundwater habitats. Otherwise, little is known of the ecology of these species.

Of note, serial sampling over a three-year period produced four species of *Diacyclops* from the Bou-Rouch pumpwell placed in a gravel bar on the Blue River in southern Indiana. These were *D. sororum* in 1997, *D. conversus* and *D. yeatmani* in 1998, and *D. nearcticus* in 2000 (Lewis 1998, Reid 2004).

One of the typical habitats of *D. nearcticus* is the hyporheos of streams (Strayer and Reid, 1999). In Indiana it has been found, using a Bou-Rouch pumpwell, inhabiting the hyporheic zone of the Blue River, as well as the interstices of stream gravel in Bond Cave, in Orange County. This species has been otherwise found over a broad range in the eastern United States, encompassing an area from Massachusetts to the Great Lakes and south to Florida. The distribution is sporadic and it has never been found in abundance at any site. In Florida, it is found in the Everglades karst in seasonally dry solution holes (Bruno et al. 2000).

Another very widespread species is *D. chrisae,* which in Indiana was found in White County just north of the Wisconsinan glacial maximum. It was previously known only from interstitial sediments in eastern Maryland and Ontario (Reid 1992).

Second to *Diacyclops*, cyclopoids of the genus *Acanthocyclops* were the most frequently recorded copepod inhabitants of groundwaters. *Acanthocyclops robustus* is generally considered a species of surface waters, but inspection of Appendix 1 shows it to be the most frequently collected of any of the copepods encountered. Some of the collection sites are remote from any point of surface input. This "surface" species is apparently very comfortable in groundwaters. A total of seven species of *Acanthocyclops* were recorded, suggesting that the group as a

whole has more than a passing relationship to groundwater habitats. For example, the rare but widespread species *Acanthocyclops parasensitivus* was found in a seep in Indiana, where it emerges from saturated interstices of gravel, and from drip pools of epikarstic origin in a cave in Tennessee. Several of the species of *Acanthocyclops* are apparently stygophilic or perhaps phreatophilic.

Appendix 1 includes a number of species that are, without a doubt, common fauna of surface habitats. Some, such as *Acanthocyclops brevispinosus, Acanthocyclops einslei, Eucyclops agilis,* and *Eucyclops conrowae,* are reported herein primarily from springs, rather than windows into deeper groundwaters. These collections represent copepods that are visitors to groundwater, but may find the cool, environmentally stable spring pools to be suitable habitat. The calanoid *Skistodiaptomus pallidus* may well be only an accidental traveler through groundwater conduits. The group consisting of *Osphranticum labronectum, A. vernalis, M. albidus,* and *Orthocyclops modestus*, found in a pool in Patton Cave, Tennessee, is typical of small, surface waterbodies, and may have entered through seepage from a nearby lake.

Contrary to what might have been expected for the strictly benthic harpacticoids, most of the species found are very widespread and common in surface habitats in North America. Members of the genera *Attheyella*, *Bryocamptus*, and *Moraria* are especially common in spring seeps and wet moss. The exception is *Bryocamptus morrisoni* s.str., which is known only from two cave-river collections in Indiana and Kentucky.

Finally, of the genera in our list, *Rheocyclops* and *Itocyclops* remain the most enigmatic. *Rheocyclops indiana* was first discovered in a drip pool in Ladder Cave, Washington County, Indiana, in the company of an undescribed species of the amphipod genus *Stygobromus*. This *Rheocyclops* was subsequently found in a drip pool in Elrod Cave, Orange County. The first impression was that this species was probably endemic to epikarstic habitats in the south-central karst belt of southern Indiana. This notion was eliminated with the discovery by Reid (unpublished data) of *R. indiana* from two hyporheic habitats in the Great Smoky Mountains National Park. These finds suggest that this species is relatively widespread, but rarely collected, probably because of its cryptic nature and small size.

Itocyclops yezoensis was formerly known from Japan and Alaska, when it was subsequently reported from Great Smoky Mountains National Park, in Sevier County, Tennessee (Reid and Ishida 2000); and recently from a streambank in Henry County, southern Virginia (Reid 2006). Although we were surprised at the range extension of Rheocyclops from Indiana to the Smoky Mountains, this distance pales in comparison to that of *I. yezoensis.* A second North American species of *Itocyclops* was recently discovered in caves that lie in the path of an interstate highway project in eastern Kentucky (Lewis and Lewis 2006a), and also in a cave in north-central Tennessee (present report). The third known species of the genus was found in a spring seep in western Virginia (Reid, in review).

PROCESSES OF SUBTERRANEAN INVASION

In Indiana, where our sampling has been most concentrated, the availability of aquatic habitats can be estimated by the glacial history of the state. The glacial history of Indiana (summarized here from IGS 2007) is quite complex and the record is incomplete, as successive ice sheets eroded the deposits of the previous glacial advances and created discontinuities in the geologic record. The present theory of glacial geologists is that the ice sheets initially progressed along valley systems during the Tertiary, in the area now comprising the boundary between the U.S. and Canada. As the glaciers moved southward, these valleys were carved into large basins that would become the present-day Great Lakes. The orientations of these basins in turn strongly influenced the direction and magnitude of glaciations in Indiana.

The climatic record derived from cores of extant glaciers in Greenland as well as ocean floor geochemical evidence suggest 12-18 periods over the last two million years that were cold enough to form continental glaciers. In Indiana, there is evidence that at least 11 distinct glacial events occurred. These are divided into three major stages, each of which had several ice advances:

(1) pre-Illinoian Stage, which is the least understood because of erosion and burial of the deposits. It comprises the period between initial glaciation and the Illinoian (700,000 - 300,000 years before present [BP]). The first Pleistocene ice sheet to reach Indiana appears to have entered the state from directly to the north (now Michigan). The glacier, thought to have been between a half mile and a mile (0.8-1.6 km) thick at the leading edge, moved slowly as it encountered bedrock hills and valleys that slowed its progress. The Teays River valley, the major drainage conduit for the eastern U.S., was 200-400 feet (60-120 m) deep prior to glaciation. After burying this large stream valley, the first glacier stopped about mid-state, then slowly receded to the north.

(2) Illinoian Stage, of which deposits are today exposed on the surface in southeast and southwest Indiana, lasted from about 300,000 to 140,000 years BP. The southeastern Indiana karst was completely glaciated during this stage. The area comprising the south-central karst area remained ice-free, but the limestone band continues to the north where it is buried under the till plain. During the subsequent Sangamon interglacial, the flattened topography of the southeastern karst was dissected to some extent by streams down-cutting through the till. The modern-day Ohio River was formed and became a major drainage conduit for the water from the melting glaciers.

(3) Wisconsin Stage, from about 50,000 to 10,000 years ago. The northern half of Indiana is covered with deposits of this age. The caves in the southeastern Indiana karst region lie under Illinoian till, but almost all occur south of the Wisconsinan glacial boundary. The occurrence of enterable caves ends near where the limestone strata meet the edge of the Wisconsinan glacial boundary in Decatur County, although other caves may certainly exist buried under the carpet of till.

Thus, different areas of Indiana, including the two karst areas, have been free of glaciers for relatively well-established time periods. The south-central karst has been ice-free and suitable, at least in that respect, throughout the Pleistocene. The southern-most area of the southeastern karst, in Clark, Jefferson, Jennings, and Ripley counties, was available from the Sangamon onward. The sites sampled in Vermilion Co., Illinois and White Co., Indiana both lie on Wisconsinan -age till plains.

This brings us to a point of controversy in the theories concerning the zoogeography and evolution of subterranean crustaceans in glaciated North America. How did tiny, substrate-bound animals such as *Diacyclops yeatmani, D. indianensis, D. salisae, D. lewisi,* or the more heavily collected (because they are easily visible to the naked eye) amphipod *Bactrurus mucronatus* and isopod *Caecidotea kendeighi* get to their present-day ranges deep within the glaciated areas? Two hypotheses have been advanced to account for this distribution pattern (Holsinger 1978, 1981, 1986; Lewis 1983, Lewis and Bowman 1981, Koenemann & Holsinger 2001): (1) survival under the ice; (2) dispersal from areas that remained ice-free after the retreat of the glaciers.

These authors have recognized that some combination of the two processes might well have occurred. We elaborate on a refinement of this idea. The continental glaciers were essentially rivers of slowly flowing ice, moving southward from their sources. It is thought that after the initial glaciation of Indiana, subsequent glaciers moved relatively quickly due to abundant water at the base of the glacier that served to lubricate the ice sliding over previously glaciated terrain. At the front edge of the glacier, the ice was constantly melting. During periods when melt rates were slow, the glaciers advanced, but receded when melting outpaced deposition of new ice.

Aquatic habitat for cold-stenothermic crustaceans should have been abundant. Peripheral to the glaciers, suitable habitat might have been available in three areas: (1) streams and meltwater lakes in front (south) of the glaciers; (2) the leading edge of the glacier where melting was occurring; (3) underneath the glacier, particularly in a zone behind the leading edge.

If the glaciers were in fact moving on a lubricating base of liquid water, if other factors were not limiting (e.g., dissolved oxygen, nutrients, scouring), then we see no reason to think that crustaceans would not have been present, particularly in the zone under the edge of the glacier. Beyond the glacier, meltwater lakes should have provided ideal habitats. This meltwater zone would have traveled northward with the receding glaciers, and the community present in it would have migrated northward as well. This would account for the presence of stygobiont species such as *Diacyclops yeatmani* and *D. chrisae* far north of the glacial maxima.

As the present interglacial proceeded, the disappearance of meltwater lakes in southern Indiana would have encouraged the invasion of the other, major aquatic habitat that remained available: groundwater. When lakes and streams draining from the receding glaciers dried, some of the cyclopoids followed the water into the interstices of the saturated glacial till. Evidence for this is the presence of *Diacyclops salisae* and *D. lewisi* in this habitat today. Robertson and Milner (2006) reported that *Diacyclops* spp. were the most characteristic members of the meiofauna in newly formed meltwater streams (ca. 50 years post recession of the glacier) in Glacier Bay National Park, Alaska.

Eleven species of *Diacyclops* have now been found during sampling of groundwater habitats in Indiana. Reid and Strayer (1994) reviewed the morphological modifications seen in subterranean copepods, some of which are noted in Table 1. Of the species of *Diacyclops* known from Indiana, *D. crassicaudis brachycercus* and *D. navus* exhibit slight or no morphological adaptations to subterranean life, and are most often found in epigean habitats. *Diacyclops lewisi* and *D. salisae* are also relatively unmodified, and occur in wells. *Diacyclops nearcticus* and *D. sororum* occur in both epigean situations and hyporheic sediments. *Diacyclops chrisae, D. conversus, D. indianensis,* and *D. yeatmani* have been found in deep interstitial and hyporheic situations. *Diacyclops jeanneli* occurs mainly in cave pools, but as suggested above may well be an inhabitant of the epikarst. Most of these lat-

ter species exhibit at least some morphological modifications.

For subterranean cyclopoid copepods found in Indiana, Table 1 summarizes a comparison of morphological adaptation as a function of the length of time available for colonization of the region. Of the *Diacyclops* species, *D. jeanneli* and *D. conversus* are the most strongly modified for subterranean existence, and both occur only in the unglaciated area of south-central Indiana. Indeed, *D. jeanneli* has been found to the very edge of the limit of Illinoian glaciation on the sides of the Knobstone Escarpment in Clark and Floyd counties. Strayer and Reid (1999) analyzed the distribution of hyporheic cyclopoids in glaciated versus unglaciated areas in the eastern United States, and noted a break in species composition associated with the Pleistocene glacial maxima. They suggested that the more specialized interstitial species, such as *Diacyclops jeanneli* and members of *Rheocyclops*, have been unable to disperse into the glaciated regions. Our sampling data lend some additional evidence to this theory, although the correlation is clouded by the differences in microhabitat preferences among the species. Further evidence is provided by the near-absence of a specialized subterranean harpacticoid fauna in this region, where, apparently, mainly the most adaptable generalist species were able to reach the subterranean habitats.

Tab. 1. Species of Diacyclops, Megacyclops, and Rheocyclops known to inhabit different regions in Indiana, according to the length of time available since the last glaciation in that region, and the degree of morphological modification of each species. The degree of modification is estimated according to the number of several characters (total given in parentheses): oligomerization of the antennular segments, loss of one or more antennal basipodite setae, oligomerization of segments of the swimming legs, shortening of the terminal endopodite segment of the leg 4 endopodite, and the anal operculum posteriorly produced.

Time of last glaciation	*Species*	*Relative degree of modification*
Unglaciated	Megacyclops donnaldsoni	Slight (1)
	Diacyclops navus*	None
	Diacyclops crassicaudis brachycercus*	Moderate (2)
	Diacyclops nearcticus*	Moderate (2)
	Diacyclops yeatmani	Moderate (2)
	Diacyclops conversus	Moderate (3)
	Diacyclops jeanneli	Moderate (3)
	Rheocyclops indiana	Advanced (4)
Illinoian glaciation, ice-free ca. 140,000 years BP	Diacyclops lewisi	None
	Diacyclops salisae	None
	Diacyclops indianensis	Moderate (2)
Wisconsinan glaciation, ice-free ca. 10,000 years BP	Diacyclops chrisae*	Moderate (2)
	Diacyclops yeatmani	Moderate (2)

* Also occurs in previously glaciated regions elsewhere in North America.

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Appendix 1. Most of the following records of copepods from groundwater habitats in and near the Interior Low Plateaus are taken from the unpublished reports of Lewis, and Lewis et al. (1996-2006). Records from Kofoid (1899), Chappuis (1929, 1931), Yeatman (1964), Barr (1967), Bunting (1973), Strayer & Reid (1999), and Reid (2004) have also been included.

ORDER COPEPODA
SUBORDER CYCLOPOIDA
FAMILY CYCLOPIDAE

Acanthocyclops brevispinosus (Herrick, 1884)
ILLINOIS: Monroe Co.: Camp Vandeventer Spring.

A*canthocyclops einslei* Mirabdullayev & Defaye, 2004
ILLINOIS: Monroe Co.: Bat Sump Cave; INDIANA: Greene Co.: Rankin Spring.

Acanthocyclops exilis (Coker, 1934)
KENTUCKY: Edmonson Co.: Mammoth Cave (Barr 1967).

Acanthocyclops parasensitivus Reid, 1998
INDIANA: Clark Co.: Seep spring, Burns Hollow; TENNESSEE: Grundy Co.: Big Mouth Cave; KENTUCKY: Pulaski Co.: Buck Creek, sandbar (Strayer & Reid 1999).

A*canthocyclops robustus* (G.O. Sars, 1863)
ILLINOIS: Monroe Co.: Bat Sump Cave; INDIANA: Harrison Co.: Baker Hollow Cave, Black Medusa Cave, Bussabarger's Cave, Harrison Cave Spring,

Harrison Spring, Stygian River Cave, Wallier Cave; Jefferson Co.: well, Grapevine Branch section 19, Big Oaks National Wildlife Refuge (BONWR); Lawrence Co.: Buddha Cave, Burton Hollow Cave, Henshaw Bend Cave; Orange Co.: Wesley Chapel Gulf Cave; Washington Co.: Endless Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931); TENNESSEE: White Co.: Lost Creek Cave.

Acanthocyclops venustoides (Coker, 1934)
INDIANA: Crawford Co.: well at abandoned house on road to Mesmore Cliffs area; Harrison Co., Bussabarger's Cave; Jefferson Co.: well, NE quarter-section 7, Big Creek drainage, BONWR; White Co.: Field drain tile outlet, 5.3 km west of Brookston; ILLINOIS: Vermilion Co.: drain tile outlet near Jordan Creek (Yeatman 1964).

Acanthocyclops vernalis (Fischer, 1853)
INDIANA: Clark Co.: Seep spring on stream bank, Burns Hollow; ILLINOIS: Monroe Co.: Bat Sump Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931); TENNESSEE: Grundy Co.: Bigmouth Cave (Yeatman 1964); Rhea Co.: Marler Cave; Rutherford Co.: Patton Cave, pool; Jackson Co.: Haile Cave, rimstone pools; ILLINOIS: Vermilion Co.: drain tile outlet near Jordan Creek (Yeatman 1964).

Diacyclops bicuspidatus (Claus, 1857)
KENTUCKY: Edmonson Co.: Mammoth Cave (Kofoid 1899). This record may refer to *D. thomasi* (S. A. Forbes, 1882), which was long considered a subspecies of *D. bicuspidatus,* and was frequently confused with the former in the earlier North American literature. Both *D. bicuspidatus* and *D. thomasi are widespread in North America;* D. thomasi is much more common, especially in the plankton of lakes and ponds, and also occurs in smaller waterbodies such as rock pools. This record is not treated further herein.

Diacyclops chrisae Reid, 1992
INDIANA: White Co.: Field drain tile outlet, 5.3 km west of Brookston.

Diacyclops conversus Reid, 2004
INDIANA: Crawford Co.: Bou-Rouch pumpwell on Blue River.

Diacyclops crassicaudis brachycercus Kiefer, 1927
INDIANA: Harrison Co.: Hiser Spring Cave.

Diacyclops jeanneli Chappuis, 1929
INDIANA: Clark Co.: Seep spring in Burns Hollow; Crawford Co.: Marengo Cave; Floyd Co.: well, New Albany near Indiana University Southeast; Harrison Co.: Devils Graveyard Cave; Orange Co.: Apple Cave, Murray Spring Cave, Tucker Lake Spring Cave; Washington Co.: Fredericksburg Cave.

Diacyclops indianensis Reid, 2004
INDIANA: Jefferson Co.: Henry Dilk Falls Cave; TENNESSEE: Fentress Co.: Redbud Cave; Franklin Co.: Crownover Saltpeter Cave, Keith Cave, Little Crow Creek Cave; Grundy Co.: Big Mouth Cave, Dry Cave; Pickett Co.: Bunkum Cave.

Diacyclops lewisi Reid, 2004
INDIANA: Jefferson Co.: well in Big Creek drainage section 7, BONWR: Jennings Co.: well in Graham Creek drainage section 18, BONWR.

Diacyclops navus (Herrick, 1882)
INDIANA: Floyd Co.: abandoned cistern near intersection of I-265 and Grant Line Road; Gibson Co.: well 5.6 km east of Fort Branch.

Diacyclops nearcticus Kiefer, 1934
INDIANA: Crawford Co.: Bou-Rouch pumpwell on Blue River; Orange Co.: Bond Cave; KENTUCKY: Pulaski Co.: Stab Cave; TENNESSEE: White Co.: Lost Creek Cave; DeKalb Co.: Smith Fork, gravel bar (Strayer & Reid 1999).

Diacyclops salisae Reid, 2004
INDIANA: Jennings Co.: well, Otter Creek drainage, section 31, BONWR.

Diacyclops sororum Reid, 1992
INDIANA: Crawford Co.: Bou-Rouch pumpwell on Blue River; Harrison Co.: Squire Boone Caverns; KENTUCKY: Pulaski Co.: Buck Creek, sandbar (Strayer & Reid 1999).

Diacyclops yeatmani Reid, 1988
INDIANA: Crawford Co.: Bou-Rouch pumpwell on Blue River; TENNESSEE: Grundy Co.: Big Mouth Cave (Yeatman 1964, as *Cyclops clandestinus)*; Van Buren Co.: Camps Gulf Cave, Swamp River Cave; ILLINOIS: Vermilion Co.: drain tile outlet near Jordan Creek (Yeatman 1964).

Diacyclops undescribed species
KENTUCKY: Pulaski Co.: Blowing Cave.

Eucyclops agilis (Koch, 1838)
ILLINOIS: Monroe Co.: Haney Spring; INDIANA: Greene Co.: Rankin Spring; Orange Co.: Rise of Lost River at Orangeville; KENTUCKY: Edmonson Co.: Mammoth Cave [Kofoid 1899, Chappuis 1931 (as E. serrulatus), Barr 1967]; Pulaski Co.: Buck Creek, sandbar (Strayer & Reid 1999); TENNESSEE: Grundy Co.: Bigmouth Cave (Yeatman 1964); DeKalb Co.: Smith Fork, gravel bar (Strayer & Reid 1999); Rutherford Co.: Herring Cave.

Eucyclops conrowae Reid, 1992
INDIANA: Harrison Co.: Firetail Spring; Orange Co.: Rise of Lost River at Orangeville.

Eucyclops elegans (Herrick, 1884)
INDIANA: Crawford Co.: Marengo Cave; Greene Co.: Rankin Spring; Monroe Co.: Harp Spring Cave; Orange Co.: Rise of Lost River at Orangeville; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931); TENNESSEE: White Co.: Lost Creek Cave.

Itocyclops undescribed species
KENTUCKY: Pulaski Co.: Sheep Cave South, rimstone pool; Stab Cave, rimstone pool; Redbud Cave, rimstone pool; TENNESSEE: Jackson Co.: Dud Cave, shallow drip pool.

Macrocyclops albidus (Jurine, 1820)
ILLINOIS: Monroe Co.: Bat Sump Cave; INDIANA: Greene Co.: Ashcraft Cave; Lawrence Co.: Buddha Cave; Monroe Co.: Well Cave; Orange Co.: Rise of Lost River at Orangeville; KENTUCKY: Edmonson Co.: Mammoth Cave (Kofoid 1899); TENNESSEE: Rutherford Co.: Herring Cave, pool; Patton Cave, pool.

Macrocyclops fuscus (Jurine, 1820)
INDIANA: Greene Co.: Rankin Spring; Harrison Co.: Stygian River Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931, Barr 1967).

Megacyclops donnaldsoni (Chappuis, 1929)
INDIANA: Crawford Co.: Hidden Spring Cave, Wildcat Cave; Lawrence Co.: Donnaldson Cave (Chappuis 1931); KENTUCKY: Edmonson Co.: Mammoth Cave, Roaring River (Barr 1967); TENNESSEE: Grundy Co.: Dry Cave; McMinn Co.: unnamed cave (Bunting 1973).

Megacyclops latipes (Lowndes, 1927)
INDIANA: Harrison Co.: Rands Spring; Monroe Co.: Well Cave; TENNESSEE: Grundy Co.: Big Mouth Cave, Trussell Cave; Rhea Co.: Marler Cave.

Megacyclops undescribed species
INDIANA: Martin Co.: Bluff House Cave; Orange Co.: Campground Cave.

Mesocyclops edax (S.A. Forbes, 1891)
ILLINOIS: Monroe Co.: Camp Vandeventer Spring, Camp Vandeventer Cave; INDIANA: Crawford Co.: Hidden Spring Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931; Barr 1967).

Microcyclops rubellus (Lilljeborg, 1901)
ILLINOIS: St. Clair Co.: Stemler Cave; INDIANA: Crawford Co.: Bou-Rouch pumpwell on Blue River; KENTUCKY: Pulaski Co.: Buck Creek, sandbar (Strayer & Reid 1999); TENNESSEE: DeKalb Co.: Smith Fork, gravel bar (Strayer & Reid 1999).

Orthocyclops modestus (Herrick, 1883)
ILLINOIS: Monroe Co.: Bat Sump Cave; INDIANA: Crawford Co.: well at abandoned house near Mesmore Cliffs; Harrison Co.: Binkley Cave; Jefferson Co.: well, Grapevine Branch section 19, BONWR; TENNESSEE: Rutherford Co.: Patton Cave, pool; Grundy Co.: Bigmouth Cave (Bunting 1973).

Paracyclops canadensis (Willey, 1934)
INDIANA: Crawford Co.: Carnes Mill Spring Cave.

Paracyclops chiltoni (Thomson, 1882)
INDIANA: Harrison Co.: Binkley Cave, Rands Spring; Lawrence Co.: Henshaw Bend Cave; Washington Co.: Mill Cave; KENTUCKY: Edmonson Co.: Mammoth Cave [Chappuis, 1931, reported *P. finitimus* Kiefer, 1929, but Chappuis' record was interpreted by Barr, 1967 as *P. fimbriatus* (Fischer, 1853). *Paracyclops finitimus* is currently considered a junior subjective synonym of *P. chiltoni,* and *P. fimbriatus* is not thought to occur in the Americas; see Karaytug & Boxshall 1998]; Pulaski Co: Buck Creek, sandbar (Strayer & Reid 1999).

Rheocyclops indiana Reid, 1999
INDIANA: Orange Co.: Elrod Cave; Washington Co.: Ladder Cave.

Rheocyclops undescribed species
ALABAMA: Jackson Co.: Russell Cave (Russell Cave National Monument).

Tropocyclops extensus Kiefer, 1931
INDIANA: Harrison Co.: Bussabargers Cave, Squire Boone Caverns.

Tropocyclops prasinus (Fischer, 1860)
KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931). Chappuis' record of *T. prasinus* may refer to the subspecies *mexicanus* later described by Kiefer.

Tropocyclops prasinus mexicanus Kiefer, 1938
ILLINOIS: Monroe Co.: Camp Vandeventer Spring, Camp Vandeventer Cave; INDIANA: Washington Co.: Endless Cavern; KENTUCKY: Edmonson Co.: Mammoth Cave (Barr 1967).

SUBORDER HARPACTICOIDA
FAMILY CANTHOCAMPTIDAE

Attheyella (Neomrazekiella) illinoisensis (S. A. Forbes, 1882)
INDIANA: Crawford Co.: Megenity Peccary Cave; Monroe Co.: May Cave.

Attheyella (Neomrazekiella) nordenskioldii (Lilljeborg, 1902)
ILLINOIS: Monroe Co.: Haney Spring, Metter Cave; INDIANA: Clark Co.: seep spring in Burns Hollow; Crawford Co.: Wymans Cave; Harrison Co.: Rands Spring; Jefferson Co.: well, NW quarter-section 18, Graham Creek drainage BONWR; Monroe Co.: Shirley Springs, Waterfall Cave; Washington Co.: Karens Pit Cave; Orange Co.: Garlow Spring Cave.

Attheyella (Ryloviella) pilosa Chappuis, 1929
INDIANA: Clark Co.: seep spring in Burns Hollow; Crawford Co.: Wymans Cave; Harrison Co.: Squire Boone Caverns; Monroe Co.: Waterfall Cave; Washington Co.: Baynes Spring Cave, Endless Cavern, Nevin Spring Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Chappuis 1931).

Bryocamptus (Bryocamptus) newyorkensis (Chappuis, 1927)
TENNESSEE: Jackson Co.: Dud Cave, shallow drip pool.

Bryocamptus (Limocamptus) morrisoni morrisoni (Chappuis, 1929)
INDIANA: Lawrence Co.: Donnaldson Cave (Chappuis 1929, 1931).

Bryocamptus (Limocamptus) morrisoni elegans (Chappuis, 1929)
KENTUCKY: Hart Co.: Horse (Hidden River) Cave (Chappuis 1929, 1931).

Bryocamptus (Limocamptus) nivalis (Willey, 1925)
INDIANA: Harrison Co.: Harrison Cave Spring.

Bryocamptus (Limocamptus) undescribed species
TENNESSEE: Overton Co.: Mill Hollow Cave.

Moraria cristata Chappuis, 1929
INDIANA: Lawrence Co.: Donnaldson Cave (Chappuis 1931).

SUBORDER CALANOIDA
FAMILY CENTROPAGIDAE

Osphranticum labronectum S. A. Forbes, 1882
TENNESSEE: Rutherford Co.: Patton Cave, pool.

FAMILY DIAPTOMIDAE

Skistodiaptomus pallidus (Herrick, 1879)
INDIANA: Harrison Co.: Harrison Cave Spring, Stygian River Cave; KENTUCKY: Edmonson Co.: Mammoth Cave (Barr 1967)

COBISS: 1.01

KARST AND WORLD HERITAGE STATUS

KRAS IN STATUS SVETOVNE DEDIŠČINE

Elery HAMILTON-SMITH[1]

Abstract UDK 502.13:551.44(100)
001:061.1(100):551.44

Elery Hamilton-Smith: Karst and World Heritage Status

Approximately 50 karst sites are now inscribed on the World Heritage Register, but many of these are inscribed on the basis of their non-karst values. Karst systems, of course, have a very wide range of values in themselves, including their remarkable biodiversity and their cultural significance, sometimes spanning many thousands of years. Today, the World Heritage Committee and UNESCO have asked that consideration be given to determining both a strategy for the nomination of new sites and a basis for priority setting in the selection of potential sites. This paper reviews current trends and emerging new patterns in World Heritage selection, assessment and management, then summarises the values of current karst WHAs in the European region.

Key words: UNESCO, Karst World Heritage, World Heritage selection, Europe.

Izvleček UDC 502.13:551.44(100)
001:061.1(100):551.44

Elery Hamilton-Smith: Kras in status svetovne dediščine

Trenutno vsebuje seznam svetovne dediščine okoli 50 kraških krajev, toda precej jih je bilo vpisanih v seznamu zaradi drugih, »nekraških« posebnosti. Kraški sistemi imajo zelo širok razpon vrednosti sami po sebi, vključno njihovo izrazito biološko raznovrstnost in kulturni pomen, ki lahko obsega cela tisočletja. Danes želita tako Odbor za svetovno dediščino kot UNESCO, da bi določili tako strategijo za imenovanje novih krajev kot tudi osnove za določanje prednosti možnih krajev za vpis. Prispevek daje pregled preko trenutnih smeri in novih vzorcev, ki se pojavljajo pri izboru, ocenjevanju in imenovanju svetovne dediščine, ter povzema pomen trenutne kraške svetovne dediščine v Evropi.

Ključne besede: UNESCO, kraška svetovna dediščina, način izbora svetovne dediščine, Evropa.

A HISTORICAL INTRODUCTION

There has always been a sense of heritage in the passing on of lands and buildings from one generation to the next; as major public lands became collective or national properties, so they too were formally passed from generation to generation. Some lands and buildings were seen as being sacred, and often recognised across many nations. There were also places that were preserved for the rich and powerful to use as their exclusive hunting grounds. Others were recognised as places of special beauty, and they too may have been set aside as nature preserves in their own country.

The values and interests underlying the preservation of these many sites started to come together at a world level following World War II. Some of this was probably due to specific events, such as the virtual destruction of the City of Dresden, which heightened awareness of what might be lost if we failed to pay proper respect to important places. This was finally crystallised in 1960 by the leadership of the then director of UNESCO, René Maheu, in saving the Abu Simbel monuments from inundation by the Aswan Dam.

Discussions over the next 10 years led to UNESCO, with the support of ICOMOS, developing a concept plan for recognition of monumental sites of cultural endeavour as "sites of universal human value". Then a parallel concept grew up within IUCN that focused upon sites

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of exceptional natural value. These two somewhat different plans were then integrated, and in 1972, the World Heritage Convention was established as an international agreement, and implemented through UNESCO.

Since then, 788 sites have been assessed and judged worthy of inclusion on the World Heritage Register. Most are recognised as either cultural or natural, but the number that are recognised as having both cultural and natural values has increased and a further category of sites called cultural landscapes has gradually grown up since 1993.

A number of international conventions or other arrangements have arisen to further world stewardship of important values – including the 1971 Ramsar Convention on Wetlands the 1968 Man and Biosphere program, 1982 Charter for Nature, 1992 Convention on Biological Diversity,. The most recent initiative is the Geoparks program which is currently being developed in order to give special recognition to geological phenomena. This program seeks not only to ensure protection of sites of special geological interest, but to further public education.

THE BASIS OF WORLD HERITAGE INSCRIPTION

The over-riding principle upon which World Heritage inscription is based lies in the concept of "outstanding universal value". The convention states that this means "cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole".

The detailed criteria for the definition of both cultural and natural heritage and for the determination of outstanding universal value are currently under review (UNESCO World Heritage Centre 2003). Under the proposed new guidelines, the two separate sets of criteria for Cultural and Natural Heritage are replaced by a single series. Criteria (i) to (v) are specific to cultural heritage; criteria (vi) is specific to cultural landscapes and is generally used where both cultural and natural values are of significance; natural heritage is dealt with in criteria (vii) to (x). However, in integrating all the criteria into a single list, it is hoped to achieve a greater commonality and integration between natural and cultural heritage and to encourage more comprehensive assessment and nomination.

These are followed by a Statement of Conditions of Integrity and also a statement of the managerial requirements which must be meant prior to inscription. I emphasise the importance of these two sets of conditions. In my experience, they may provide a significant barrier to inscription, or if accepted without critical examination may create difficulties in future attempts to enhance the quality of management. Selected extracts from the new proposals are attached below as Annex 1.

We must also note another important trend is that, where appropriate, serial (or cluster) nominations of a group of similar sites will be preferred to a series of discrete nominations for such sites. In some cases, this may be treated as a boundary extension of an existing site, and it may also give rise to a trans-national site.

OBLIGATIONS OF THE HOST NATION

On nominating a site for World Heritage recognition, state parties undertake a number of obligations, of which the two must important at the site level are:

- Proper protection and maintenance of the site, and in particular, the values upon which registration is based
- Making access to the site available as a right to all peoples of the world

At first sight, these two sets of obligations are conflicting. Providing access often leads to degradation of a site, but that is largely the case where understanding and management capacity is limited. World experience now demonstrates that sites can and should be managed on a low-impact, high-sustainability basis. The tourism industry must learn to share in and contribute to this level of management.

As a simple example, there is now a lot of understanding of how walkways can be constructed in such a way as to minimise the impacts of infrastructure. But the application of this and related understandings depends upon quality of management. It might even be said that tourists do not create undesirable impacts – but managers do.

WORLD HERITAGE AND THE CURRENT RECOGNITION OF KARST

This paper will now focus upon karst sites and discuss some of the issues associated with these. Worldwide, there are some 50 sites that are located upon and/or feature karst phenomena (See Annex 1). Some of these were inscribed for other reasons – but that is not surprising. On one hand, many biodiversity hotspots are located on karst and on the other, the natural beauty of karst often leads to the development of important cultural traditions on karst. A comprehensive list is attached as Annex 2.

The Task Force assumes a holistic perception of karst systems, probably first spelled out explicitly by Yuan Daoxian (1988) and expressed concisely but elegantly by Eberhard (1994) as a system:

... which incorporates component landforms, life, energy flows, water, gases, soils and bedrock.

A particularly useful set of formal (English language) definitions are provided by Lowe and Waltham (2002). A valuable source of translations to other languages can be found on the WWW site of the International Union of Speleology at <http://www.uisic.uis-speleo.org/lexintro.html>.

One only has to look over the list of WH sites to see that a number of themes are important:

• Aesthetic quality: many of the listed sites are famous for their spectacular scenery or the remarkable underground beauty of the caves

• Biodiversity: the biodiversity of karst is utterly remarkable, even if often overlooked – many of those interested in biodiversity focus upon fur, feathers and flowers and ignore the remarkable adaptation, endemicity and diversity of invertebrate populations. The biodiversity upon karst is very much a result of the multitude of micro-climatic niches that are provided both on the surface and underground.

• Geo-climatic and environmental history: "Caves are the books in the library of the history of the earth". As we learn to read the language of the caves more fully, we realise that they really are a remarkable treasure house of our past. Fossils, rock art and sediments provide evidence of particular importance. Further, the patterns of limestone deposition and subsequent karstification tell us a great deal about sea-level change phenomena. In particular, caves are also a major source of geo-climatic history.

• Mineral chemistry: the beauty of cave minerals has long been recognised, but caves now provide valuable natural laboratories for exploring geodiversity and the role of micro-biota in genesis and development of minerals. Recent years have also revealed the immense diversity of stromatolites in karst areas – a life-form once thought to be long extinct.

Evidence of human use and occupation: The most obvious examples are the caves with rock art which is both extremely beautiful and also provides evidence for improving our understanding of the way in which human perceptual and conceptual processes evolved. Today, new discoveries are reported virtually every week. As I sat down to write an earlier version of this paper, my incoming e-mail reported on a British cave art discovery of great significance. More important still, we have just heard the first public announcement of the *Homo florensis* discovery.

SOME PROBLEMS

Karst commonly gives rise to some problems in World Heritage assessment.

• Many cave sites are of both cultural and natural significance but the process of assessment has often assumed only one of these to be significant and ignored the other. A number of sites already inscribed warrant further review to broaden the terms of reference for their inclusion. This is an important issue and not just a technicality. If the full significance of the site is not detailed in its citation, then both management planning and future management practice may be unaware of or ignore the unstated values.

• Traditionally, the conservation movement has focused on visible biodiversity or what can be commonly referred to as fur, feathers and flowers. Regrettably the subterranean karst has none of these characteristics, but may have particularly significant biodiversity in the resident invertebrate community. Even when this is spelled out in nomination or similar documents, it may not be accorded the significance that it properly deserves.

• A related problem is that the extremely strong focus on biodiversity tends to push aside important considerations of geodiversity. Consideration is currently being given developing a world network of geoparks and while this is a valuable proposal in itself, it may also mean geodiversity will be even more ignored within the World Heritage family.

Theme	Specific Characteristics
Overall Context of the Karst System	Regional context, continental, coastal or island situation; lithology, structure, stratigraphy, morphogenetic context, geomorphic history.
Landform Geodiversity	Enclosed depressions, such as dolines, uvalas, poljes, blind valleys, gorges, cones, towers, case hardening, karren (both bare rock and covered forms), assemblages. Hydrologic features such as sinking streams, springs, estavelles, hot springs, submarine springs, turloughs. Depositional landforms such as phytokarst, tufa and travertines, mound springs, terraces, stromatolites.
Groundwater Systems and meteorology	Flow patterns, sinks and springs. Atmospheric and climatic patterns, including microclimates.
Subterranean landforms, primarily caves	Varying plan and cross-sectional patterns, relation to aquifer, genetic types of caves, age of caves, depth and length of caves.
Cave Contents	Sediments, clastic fills, precipitates, types of speleothems. Stratigraphy of fills. Dating potentials. Palaeontology, archaeology, other cultural relics or modifications.
Surface Biodiversity	Surface flora and fauna. Invertebrates of terrestrial, freshwater and anchialine environments. Microbiota, including nanobacteria, bacteria, protozoa, algae. Issues of speciation, adaptation, and endemism.
Subsurface Biodiversity	Subterranean flora and fauna, including vertebrates, invertebrates and microbiota. Speciation, adaptation, endemism.
Cultural, religious, historical and archaeological values	Residence, spiritual or religious, artistic, refuges. Recreation and tourism, aesthetics. Research and education.
Negative human impacts	Damage to or fragmentation of system. Modification for human use - design quality and impacts. Invasive species impacts. Production, sanatoria, defiance, water supply cheese, mushrooms. Pollution and sedimentation. Hazards and health issues. Birds nest collection, Guano extraction.
Ensuring integrity	Allogenic catchment condition draining into karst. Monitoring and control of environment. Management policies and quality.

Table 1: Draft Evaluation and Assessment Hierarchical Framework

• The biodiversity of many karst areas is indeed striking. It may include a high level of plant endemism on the surface, bats or other vertebrates within the cave, terrestrial, freshwater or anchialine invertebrates and a host of microbiota. In many countries (but much less in Europe) the lack of adequate taxonomic work creates problems in site assessment. Much surface biodiversity simply reflects the geodiversity of underlying rock and soils or of microclimates. But in karst one often finds a high degree of biodiversity in what appears to be a relatively uniform environment, e.g., there are over 50 species of troglobitic dytiscid beetles described from the deeply buried calcretes of Western Australia.

• Criterion (iii) raises a specific problem, most countries with significant karst areas can claim sites of great aesthetic value and many such sites are already inscribed. The proposal from France (2000) did not, however, so much give rise to questions on this basis but rather because of problems relating to integrity and management. I know it is now in the process of being reviewed and resubmitted.

• Virtually any major karst area is likely to meet criteria (vii) and (viii). So the relative importance becomes a major issue. The current movement towards clarifying policies for future nomination has placed a strong emphasis on the definition of classes of sites and then of selecting the best example(s) from each class. Establishing such a list of classes is currently in progress but will probably take another twelve months to achieve a useful result.

• From a scientific perspective most important yet most neglected component of most caves is the floor. It may well be relatively unattractive but often contains the records of past geoclimatic change, surface vegetation, human and animal succession, geological history and, in itself, is often a valuable biological habitat. If a floor has long been trampled, consideration should be given to an elevated walkway and to an attempt to restore the qualities of the floor surface.

• The very complexity of karst often poses difficulties in assessment. The use of a hierarchical framework is increasingly recognised and the example in Table 1 is drawn from the Proceedings of the Asia Pacific Forum (Wong et al 2001).

KARST WHAS IN EUROPE.

We commence with a table of the currently inscribed sites.

Hungary / Slovakia	Caves of Aggtelek & Slovak Karst	vii
Slovenia	Škocjanske Jame	viii, ix
Bulgaria	Pirin National Park	vii, viii, ix
France / Spain	Pyrennes / Mt Perdu	**iii, iv, v,** vii, ix
Russian Federation	Lake Baikal	vii, viii, ix, x
Russian Federation	Western Caucasus	vii, viii, ix, x
Turkey	Pamukkale	**iii, iv,** ix
Yugoslavia : Montenegro	Durmitor National Park	vii, viii, x
France	Caves of the Vézère	**i, iii**
Spain	Altamira	**i, iii**
Spain	Atapuerca	**iii, iv**
Sweden	Södra Ölands Odlingslandskap	**iv, v**

Table 2: Current European Karst World Heritage Sites

In summary, six sites are inscribed only as natural heritage, three as cultural heritage, one as a cultural landscape and only two as both. At first sight these sites appear to be each satisfactorily defined and cited – but some state parties may wish to raise questions about changes to their boundaries or citations.

A further question is whether other nominations may be proposed:

• I have already noted the potential opportunity for resubmission of the French nomination of highly decorated caves.

• I understand that there has been consideration of an alpine karst nomination. It appears to me that a transboundary and possibly serial nomination should be considered rather than any multiple nationally based sites. The essential unity of the Alps should not be fragmented by political boundaries.

• Some types of karst not currently represented on the register include the sulphur-based karst adjacent to the Black Sea, karst in gypsum or halite and sites that demonstrate aspects of Neanderthal cultural behaviour.

Finally, I wish you all well in your efforts to ensure proper protection of karst sites. As chair of the IUCN task force, I will certainly be glad to assist you all in any way we can.

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ANNEX 1: SELECTED EXTRACTS FROM OPERATIONAL GUIDELINES FOR THE IMPLEMENTATION OF THE WORLD HERITAGE CONVENTION (2003)

AN OVER-RIDING PRINCIPLE

Cultural and natural heritage must be of "outstanding universal value" to be inscribed on the World Heritage List.

"Outstanding universal value" means cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole.

DEFINITION OF WORLD HERITAGE

I.C.1 The criteria for including properties in the World Heritage List should be applied in a way that is consistent with the definition of the cultural and natural heritage set out in Articles 1 and 2 of the World Heritage Convention, as reproduced below.

ARTICLE 1

For the purposes of this Convention, the following shall be considered as "cultural heritage";

monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;

groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science;

sites: works of man or the combined works of nature and of man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological points of view.

Fig. 1: Velebit Mt., an important and typical part of Dinaric karst (photo N. Zupan Hajna).

ARTICLE 2

For the purposes of this Convention, the following shall be considered as "natural heritage".:

natural features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value from the aesthetic or scientific point of view;

geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of outstanding universal value from the point of view of science or conservation;

Fig. 2: Limestone pavement, an example from Ireland shown on the picture, is a typical form of karst and needs a special protection (photo A. Kranjc).

CRITERIA FOR DETERMINING OUTSTANDING UNIVERSAL VALUE

ILC.2 A property which is nominated for inclusion in the World Heritage List will be considered to be of outstanding universal value when the Committee finds that it meets one or more of the following criteria:

(i) represent a masterpiece of human creative genius;

(ii) exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;

(iii) bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared;

(iv) is an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;

(v) is an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;

(vi) be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. The Committee considers that this criterion should preferably be used in conjunction with other criteria;

(vii) contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance.

(viii) be outstanding examples representing major stages of earth's history, including the record of life, significant on¬going geological processes in the development of landforms, or significant geomorphic or physiographic features;

(ix) be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;

(x) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation;

Fig. 3: Regarding the ice formation, the history and the long sequence of scientific observations, Kungur Ice Cave has the World importance (photo A. Kranjc).

CONDITIONS OF INTEGRITY

ILD.9 **Integrity is a measure of the wholeness and intact**ness of the natural and/or cultural heritage and its attributes. Examining the conditions of integrity, therefore, requires assessing whether or not the property:

- includes all elements necessary to express its outstanding universal value;
- is of adequate size to ensure the complete representation of the features and processes which convey the property's significance;

- is free from the adverse effects of development and/or neglect.

II.D.10 For properties nominated under criteria (i) to (vi), the physical fabric of the property and/or its significant features should be in good condition, and the impact of deterioration processes controlled. A significant proportion of the elements necessary to convey the totality of the value conveyed by the property should be included. Relationships and dynamic functions present in cultural landscapes, historic towns or other living properties essential to their distinctive character should also be maintained.

ILD.11 For all properties nominated under criteria (vii) to (x), bio-physical processes and landform features should be relatively intact. However, it is recognized that no area is totally pristine and that all natural areas are in a dynamic state, and to some extent involve contact with people. Human activities, including those of traditional societies and local communities, often occur in natural areas. These activities may be consistent with the outstanding universal value of the area where/when they are ecologically sustainable.

II.D.12 In addition, for properties nominated under criteria (vii) to (x), a corresponding condition of integrity has been defined for each criterion.

ILD.13 Properties proposed under criterion (vii) should be of outstanding universal value and include areas that are essential for maintaining the beauty of the property. For example, a property whose scenic value depends on a waterfall, would meet the conditions of integrity if it includes adjacent catchment and downstream areas that are integrally linked to the maintenance of the aesthetic qualities of the property.

ILD.14 Properties proposed under criterion (viii) should contain all or most of the key interrelated and interdependent elements in their natural relationships. For example, an "ice age" area would meet the conditions of integrity if it includes the snow field, the glacier itself and samples of cutting patterns, deposition and colonization (e.g. striations, moraines, pioneer stages of plant succession, etc.); in the case of volcanoes, the magmatic series should be complete and all or most of the varieties of effusive rocks and types of eruptions be represented.

ILD.15 Properties proposed under criterion (ix) should have sufficient size and contain the necessary elements to demonstrate the key aspects of processes that are essential for the long-term conservation of the ecosystems and the biological diversity they contain. For example, an area of tropical rain forest would meet the conditions of integrity if it includes a certain amount of variation in elevation above sea-level, changes in topography and soil types, patch systems and naturally regenerating patches; similarly a coral reef should include, for example, seagrass, mangrove or other adjacent ecosystems that regulate nutrient and sediment inputs into the reef.

ILD.16 Properties proposed under criterion (x) should be the most important properties for the conservation of biological diversity. Only those properties which are the most biologically diverse and/or representative are likely to meet this criterion. The properties should contain habitats for maintaining the most diverse fauna and flora characteristic of the bio-geographic province and ecosystems under consideration. For example, a tropical savannah would meet the conditions of integrity if it includes a complete assemblage of co-evolved herbivores and plants; an island ecosystem should include habitats for maintaining endemic biota; a property containing wide-ranging species should be large enough to include the most critical habitats essential to ensure the survival of viable populations of those species; for an area containing migratory species, seasonal breeding and nesting sites, and migratory routes, wherever they are located, should be adequately protected.

ANNEX 2: WORLD HERITAGE KARST SITES

A listing initially prepared by Elery Hamilton-Smith and Rolf Hogan, April 2001 (Updated to 2005 by EHS)

Note that the criteria shown are from the earlier separate listings for cultural and natural heritage under which inscription occurred.

World Heritage Site	State Party		Key Features	
Tasmanian Wilderness	Australia	1982	Many areas of karst in limestone and dolomite. High geodiversity and biodiversity values.	i, ii, iii, iv C iii, v, vi
Lord Howe Island	Australia	1982	Small area of karst in aeolian calcarenite and coralline limestones	iii, iv
Central Eastern Rainforests	Australia	1986	A large number of relatively small reserves, some of which include areas of impounded karst	i, ii, iv
Shark Bay	Australia	1991	Located on karst, with zones of differential salinity within the bay and outstanding display of living Stromatolites	i, ii, iii, iv
Australian Fossil Mammal Sites	Australia	1994	Vertebrate Fossil deposits at Riversleigh (Oligocene-Miocene) & Naracoorte (Pleistocene). Both have a diversity of karst landforms and Naracoorte has high current biodiversity.	i, ii
Greater Blue Mountains	Australia	2000	Includes Jenolan Caves and a number of smaller karst sites	ii, iv
Purnululu	Australia	2003	Karst landscape on quartzitic sandstones demonstrating clearly the process of cone karst formation on sandstone	i, iii
Pirin National Park	Bulgaria	1983	Various areas of karst, some of which have been shaped by glaciation	i, ii, iii
Nahanni National Park	Canada	1978	Spectacular karst landforms, including an immense gorge and caves	ii, iii
Canadian Rockies	Canada	1984	Includes Castleguard and other caves	i, ii, iii
Zhoukoudian	China	1987	Peking Man excavation site situated in ancient karst	C iii, iv
Wulingyuan Scenic and Historic Interest Area	China	1992	At least one-third of the site is on limestone, with extremely large caves and two natural bridges, one of which is 357m. high.	iii
Huanglong	China	1992	Famous for its extensive and spectacular travertine deposits; many other karst features	iii
Jiuzhaigou Valley	China	1992	Largely on dolomite with calcareous travertine	iii
Three Parallel Rivers of Yunnan Karst	China	2003	Geological history of the last 50 million years associated with the collision of the Indian Plate with the Eurasian Plate, the closure of the ancient Tethys Sea, and the uplifting of the Himalaya Range and the Tibetan Plateau.	i, ii, iii, iv

Plitvice Lakes National Park		1979 2000	Spectacular travertine barriers and lake systems; forest in excellent condition.	ii, iii
Viñales Valley	Cuba	1999	Karst landscape with conical hills (Mogotes) in a wide flat-floored valley. It is a 'type locality' of Mogote karst and has a rich subterranean biodiversity.	C iv
Desembarco del Granma National park and System of Marine Terraces of Cabo Cruz	Cuba	1999	Uplifted marine terraces and ongoing development of karst topography. Aesthetic value of stair-step terraces and cliffs	i, iii
Alejandro de Humboldt National Park	Cuba	2001	A large inland plateau which is one of the most biologically diverse island sites known. It includes both limestone karst and pseudokarst	ii, iv
Caves of the Vézère	France	1979	Some 147 identified and significant prehistoric sites, including the famous Lascaux and many other painted caves	C i, iii
Pyrenees-Mount Perdu	France/Spain	1997 1999	Alpine karst site with lakes, gorges, waterfalls, cirques and canyons	i, iii C iii, iv, v
Caves of Aggtelek and Slovak Karst	Hungary/ Slovakia	1995 2000	712 caves. Variety and concentration of cave types, speleothems and an array of typical temperate zone karst features. (Includes aragonite and sinter formations and an ice filled abyss.)	i
Lorentz National Park	Indonesia	1999	Much of the park is high altitude karst, with spectacular landforms. Regrettably, the finest of the karst is adjacent to but not yet included in the park	i, ii, iii, iv
Luang Prabang	Laos	1995	Built on karst with various landforms; a number of the caves are important temple sites.	C ii, iv, v
Tsingy de Bemaraha	Madagascar	1990	Pinnacle karst that is difficult to access; little investigation to date.	iii, iv
Gunung Mulu	Malaysia	2000	295 km explored caves, Sarawak Chamber - world's largest; Speleothems with spectacular aragonite & calcite needles. 1.5 myo sediment sequence, giant doline-karst collapse, lateral planation; Bats & swiftlets energy transfer from forest to cave; Karst, bats, pinnacle forest Forest & cave biodiversity.	i, ii, iii, iv
Chichen Itza	Mexico	1988	Religious Centre, situated around an immense cenote that was a major site of sacrificial rituals	C I, ii, iii
Luang Prabang	Laos	1995	Built on karst with various landforms; a number of the caves are important temple sites.	C ii, iv, v
Sian Ka'an	Mexico	1987	Situated on the edge of the great cenote karst of the Yucatan Peninsula. Only a small part of this karst is within the WHA.	iii, iv
Te Wahipounamu	New Zealand	1990	Includes a number of small areas of karst, including the Aurora Cave at Te Anau.	i, ii, iii, iv

Puerto-Princesa Subterranean River National Park	Philippines		Spectacular karst landscape, underground river & caves. Most significant forest in Palawan Biogeographical Province.	iii, iv
Lake Baikal	Russian Federation	1996	A major part of the watershed (Irkutsk basin) is located on Karst.	i, ii, iii, iv
Western Caucasus	Russian Federation	1999	The Northern section consists entirely of karst with some of the world's great deep and extensive caves. Some of these have important Neanderthal sites and so are of considerable archaeological value.	i, ii, iii, iv
Škocjanske Jame	Slovenia	1986	Awesome river canyons, textbook portrayal of karst hydrogeology. On-going process; Collapsed dolines & caverns .	ii, iii
East Rennell	Solomon Islands	1998	A particularly large and diverse raised coral atoll.	ii
The Fossil Hominid Sites of Sterkfontein, Swartkrans, Kromdraai, and Environs	South Africa	1999	A cluster of karst sites containing remains of some of the earliest humanoids.	C iii, iv
Altamira Cave	Spain	1985	One of the most famous and diverse collections of cave art	C i, iii
Atapuerca Caves	Spain	2000	Contains earliest and richest evidence of human beings in Europe.	C iii, iv
Södra Ölands Odlingslandskap	Sweden	2000	The only extensive area of limestone in Sweden – a large pavement with various surface karst features.	C iv,v
Thung Yai Hua Kha Khaeng	Thailand	1991	One of the various protected areas over the Western karst region – an area with great diversity and value on many criteria.	ii, iii, iv
Pamukkale	Turkey	1988	Spectacular travertine terraces	iii C iii, iv
Henderson Island	UK: Pitcairn Islands	1988	Relatively undisturbed example of a raised coral atoll.	iii, iv
Grand Canyon	USA	1979	Caves are found throughout the Redwall limestone beds and contain a great number of archaeological relics.	i, ii, iii, iv
Mammoth Cave National Park	USA	1981	Continuous cave formation (100 mya-present). Large level passages & jagged domepits. Rich troglobitic fauna.	i,iii,iv
Carlsbad Caverns National Park	USA	1995	81 caves. Huge caverns & decorative mineral features, scenic values esp. Lechuguilla. (Most types of limestone cave formation are found here, including long passages with huge chambers, vertical shafts, stalagmites, stalactites and gypsum 'flowers' and 'needles'. Excellent examples of karstification by sulphur acids. Rich microfauna.)	i, iii
Canaima National Park	Venezuela	1994	The most outstanding example in the world of karst in quartzitic sandstones.	i, ii, iii, iv

Ha Long Bay		1994 2000	Most extensive and best-known example of marine invaded tower karst and one of the most important areas of fengcong and fenglin karst in the world.	i, iii
Phong Nha Ke Bang	Vietnam	2003	One of the finest and most distinctive examples of a complex karst landform in SE Asia. Phong Nha displays an impressive amount of evidence of earth's history.	i
Durmitor National Park	Montenegro	1980	Deep limestone beds span a remarkable geological sequence. Glacial lakes, caves and the Tara Canyon dominate the landscape.	ii,. iii, iv

REPORT FROM THE WORLD HERITAGE MEETING AT CHRISTCHURCH, NEW ZEALAND,

23 JUNE-1 JULY 2007

I hope the grapevine has already brought you the good news, but just in case it hasn't, I thought I should write to let you know of considerable- but not unqualified -success concerning cave and karst sites at the World Heritage meeting in New Zealand last week. I did not have the status as an 'observer' at the meeting to be permitted to say anything in the general assembly, but I can assure you that much was said in informal sessions outside of the meeting hall.

The World Heritage Committee showed complete consensus over the World Heritage value of 'Jeju Volcanic Island and Lava Tubes', so that site is now formally inscribed on the WH list.

Kyung Sik Woo, a geologist and caver, did an enormous amount of energetic and highly professional work over several years to ensure the success of that nomination. So both he and South Korea are to be congratulated. We now have some fantastic lava tubes properly recognized and protected.

The World Heritage Committee also reached a clear conclusion over the 'South China Karst' nomination and that is also now inscribed formally on the World Heritage list. This nomination comprised three separate sites: the Shilin 'Stone Forest', the Libo cone karst, and the Wulong tiankeng-natural bridges karst. Shilin and Libo were supported without significant further discussion, but the Wulong site stimulated quite a lot of debate within the World Heritage Committee because the draft recommendation from the IUCN was that approval of the site be deferred (this was not because the IUCN did not recognize its World Heritage qualities but because they considered Furong Cave not to be of WH quality and because the boundaries of the site need further consideration to ensure effective environmental management of the tiankeng, bridges and subterranean ecosystems.

In short, the nomination needed a few amendments in detail and a rationalizing of boundaries to ensure the quality expected of WH properties).

However, it seems that the World Heritage Committee (composed of politicians, not scientists) considered that inscription could still be accepted in principle, on the understanding that the outstanding management and boundary issues could be cleared up later. I find this pragmatic approach to be entirely acceptable, provided the Chinese authorities really do make the necessary changes. The upshot of all this is that we now have three wonderful karst sites with great caves in China on the World Heritage list. This is just Phase 1 of their serial nomination. Phase 2 will follow in just a few years time with more nominations. There is still debate to come as to what sites might be included, but I am pretty sure that the iconic tower karst between Guilin and Yangshuo along the Li river will be included.

There was another caves and karst World Heritage nomination concerning parts of numerous caves rich in speleothems in France. However, the IUCN did not support the nomination and their draft recommendation was that the sites should not be inscribed on the World List. France chose to withdraw the nomination before it was formally considered by the World Heritage Committee, because that leaves open the possibility of revising the case presented and re-applying at a later date.

An important point concerning the future of cave and karst sites is that there is a feeling amongst the World Heritage Committee and IUCN that caves and karst are now very well represented on the World Heritage List. This means that it will be increasingly difficult to get new sites accepted. However, there is also a recognition that on the Natural World Heritage List in general sites located in the semi-arid and arid zones are not well represented. So there seems to me to be potential there for some new Australian and Brazilian karst sites.

Paul Williams

COBISS: 1.01

BOOKS ABOUT KARST AND SUBTERRANEAN IN AUERSPERG'S »PRINCE'S« LIBRARY OF LJUBLJANA

KNJIGE O KRASU IN PODZEMLJU V TURJAŠKI »KNEŽJI« KNJIŽNICI V LJUBLJANI

Stanislav JUŽNIČ[1]

Abstract UDC 016:551.44:027.1
027.1(497.4)(091)"16"

Stanislav Južnič: Books about karst and subterranean in Auersperg's »prince's« library of ljubljana

For the first time the karst research books at the former Ljubljanian Auersperg "Prince's" library were put at the limelight by using the recently found manuscript catalogue 1668 (transcribed in 1762) and sales catalogues of 1982 and 1983. During the baroque times of Volf Engelbert Auersperg the science of karst was not born yet. The researchers had to wait for another century until the most fundamental facts about karst were proved by Carniolan scientists Hacquet, Gruber, and others. Nonetheless Volf collected several important books about karst with famous authors Aldrovandi, Ferrante Imperato, Johann Joachim Becher, Tommasso Buoni, Jakob Joannes Wenceslaus Dobrzensky de Nigro Ponte, and Athanasius Kircher. The special concern was put on the Count Volf Engelbert and his brother Prince Janez Vajkard interests in karst phenomena and their mutual influence on the younger visitors of their Ljublanian palace, especially Schönleben and Valvasor. Volf and Janez owned several manors at now Slovenian and Croatian karst. Janez Vajkard personally managed the first systematic research of subterranean animals in Postojna cave as a part of his Postojna Manor.

Key words: Auerspergs, karst, karst literature, Baroque, Ljubljana, Slovenia.

Izvleček UDK 016:551.44:027.1
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Stanislav Južnič: Knjige o krasu in podzemlju v turjaški »knežji« knjižnici

Opisane so knjige o krasu iz nekdanje ljubljanske turjaške knežje knjižnice. Pri njihovem iskanju smo si pomagali z rokopisnim katalogom iz leta 1668, prepisanem leta 1762 ter s prodajnimi katalogi iz let 1982 in 1983. Grof Volf Engelbert je v knjižnici zbral več zanimivih in pomembnih raziskav o krasu, ki so jih spisali Aldrovandi, Ferrante Imperato, Johann Joachim Becher, Tommasso Buoni, Jakob Joannes Wenceslaus Dobrzensky de Nigro Ponte in Athanasius Kircher. Podane so primerjave z Valvasorjevo in drugimi kranjskim knjižnicami 17. stoletja. Posebej so izpostavljena znanstvena nagnjenja in usmeritve prvih lastnikov knjig, predvsem turjaškega grofa Volfa Engelberta in njegovega brata kneza Janeza Vajkarda. Podrobno je raziskan pomen njunega zanimanja za kras in vpliv na mlajše obiskovalce njune palače, med njimi predvsem Schönlebna in Valvasorja. Knjižnica služi kot osnova za razmišljanje o poznavanju krasa pri Turjačanih, ki so imeli več graščin na krasu. Lastnik postojnskega gradu knez Janez Vajkard je lastnoročno vodil prva raziskovanja podzemnega živalstva.

Ključne besede: Turjačani, kras, literatura o krasu, barok, Ljubljana, Slovenija.

INTRODUCTION

The library of the Count Volf Engelbert Auersperg was among the best private collections. He and his younger European baroque brother Prince Janez Vajkard Auesperg collected 7000 titles of the carefully selected predominantly baroque literature. There was no monograph devoted solely to the karst in their times, but Volf and his brother's books contained several important researches of the karst and subterranean phenomena. Volf's first librarian and also his best personal friend Janez Ludvik Schönleben (* 1618 Ljubljana; † 1681) classified the books into eighteen classes. The description of classes didn't mention any karst phenomena. As a geological and biologi-

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cal oriented research, the karst would fit in to the sixth class of medicine, but only Imperato's karst research was listed among the medicine books. Aldrovandi's zoology books were noted as a profane history. Kircher and Dobrzensky's books were put at the mathematical class, and Travagini's work was added to the philosophical books because the baroque philosophy still included physics.

Schönleben himself was one of the best baroque karst researchers. His book included the description of Cerknica Lake and Carniolan Caves (1681). It was eventually published eight years after Volf's death, to late to be mentioned at Volf's library catalogue (HHStA, FAA). But at least ten other Schönleben writings were catalogued and Schönleben certainly used Volf's library for his karst research.

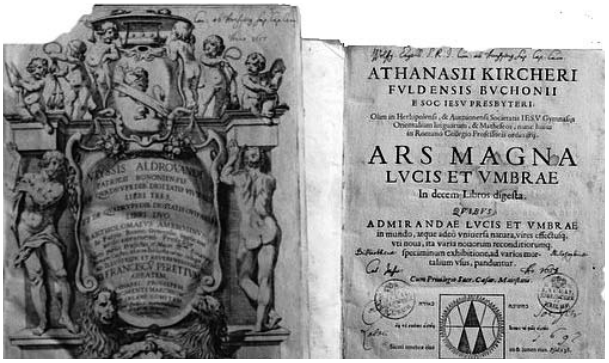

Fig. 1: Schönleben's handwriting of Volf's bookplate at the title page of Aldrovandi's description of the quadrupeds with toes, one of the five Aldrovandi's description of animals now kept at the National and University Library of Ljubljana (Aldrovandi 1637). On the right side is Kircher's optics with Schönleben's handwriting of Volf's exlibris above the later Ljubljanian Jesuit bookplate (Kircher 1646).

Sl. 1: Schönlebnov vpis turjaškega ekslibrisa na naslovnici Aldrovandijevega opisa štirinožcev s prsti. Eden od petih Aldrovandijevih opisov živalstva iz zbirke Volfa Engelberta Turjaškega v današnjem NUKu na prostorih nekdanje turjaške knežje knjižnice (Aldrovandi 1637). Na desni je Schönlebnov vpis turjaškega ekslibrisa na naslovnici Kircherjeve Svetlobe in sence s prepisom na ljubljanske jezuite 39 let pozneje (Kircher 1646).

ULYSSE ALDROVANDI

(Ullisse, * 1522 Bologna; † 1605 Bologna)

Aldrovandi was the director of Botanical Garden, professor of logic and medicine at the University of Bologna. He developed the first well off Natural History Museum, although the Botanical Gardens at Padua and Pisa were established somewhat earlier (Lines 2006, 132, 140).

Aldrovandi was the most influential zoologist of his time with special interest at the subterranean (Shaw 2001, 286). Volf bought many Aldrovandi's books, and his brother's descendants added eleven more according to the catalogue listing of February 5, 1761 (HHStA, FAA, 416). Just five of those books are now kept at the National and University Library of Ljubljana. All five were published after Aldrovandi's death. By mere chance the building of National and University Library stands almost at the same place once occupied by Auersperg "Prince's" palace with a library.

Publication	*Title and Place of Publication*	*HHStA, FAA page, class*
1599, 1602, 1603	Orinthologia sive hist. De avibus, tom 1-3. Bologna	265, Profane History
1602	De insecti.	266, Profane History
1616, 1631, 1621	De quadrupedibus.	266, Profane History
1606	Animalibus exanquibus.	266, Profane History
1613	De piscibus et cetis. Bologna	266, Profane History
1640	De serpentis et dragonis. Bologna	266, Profane History
1599	De monstris & paralipomeni. Bologna	266, Profane History
	11 books	416, added 1761

Table 1: Aldrovandi's books in Auersperg's "Prince's" library

FERRANTE IMPERATO

(* 1550 Naples; † 1625 Naples)

Volf bought several Academy *dei Lincei* and its member Galileo's books. Several Volf's authors were the Academy *dei Lincei* members from Naples. Volf didn't buy G.B. Stelluti's review of very influential Porta's *De Humana Physiognomia* (1586) or Stelluti's book about honeycomb (1625). Nonetheless Volf bought three Porta's books and one of Porta's fellow Naples citizen Imperato. The Karst researcher Imperato was also a member of Academy *dei Lincei*.

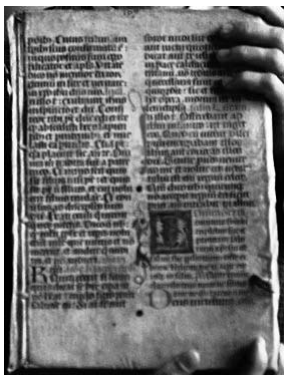

Fig. 2: The older illuminated handwriting as a cover of Aldrovandi's description of quadrupeds with toes (Aldrovandi 1637).

Sl. 2: Starejši okrašeni rokopis na platnici Aldrovandijevega opisa štirinožcev s prsti (Aldrovandi 1637).

Naples apothecary Ferrante Imperato of Academy dei Lincei published his Natural History with the description of subterranean and other waters (Imperato 1559, 196-198, 215-219; Shaw 2001, 286; Sotheby's 1982, 56; Müller 1998, 138-139), and Volf did not hesitate to buy the item. Ferrante published 640 pictures showing all three Natural History kingdoms beginning with the crystals, fossils of plants, fossils of animals, corales, and fungus (Imperato 1599, 643-734). The real nature of fungus was certainly not widely known in his times. On next pages Imperato described the plants (Imperato 1599, 756-777) and finally animals beginning with cuttlefishes and fishes (Imperato 1599, 778). The perfectly documented book full of lively observations simply had to attract a collector like Volf. Even in the later edition published shortly before Volf's death the editors included again a copperplate with Ferrante's Natural History cabinet during the demonstration.

Fig. 3: The title page of Imperato's Natural History (Imperato, 1599).

Sl. 3: Naslovna stran Imperatovega Naravoslovja (Imperato, 1599).

Fig. 4: The handy-colored two page copperplate of Imperato's museum in Naples with a rich library and different natural history curiosities during the demonstration for visitors (Imperato 1599).

Sl. 4: Ročno barvan dvostranski bakrorez Imperatovega muzeja v Neaplju z bogato knjižnico in raznovrstnimi naravoslovnimi znamenitostmi med demonstracijo obiskovalcem (Imperato 1599).

At the year of Volf's birth (1610) Ferrante's son Francesco Imperato published a book about minerals (Thorndike 1958, 7, 247) showing that an apple doesn't fall far from a tree. He inherited at last some of his father abilities.

Besides Ferrante's description of the subterranean waters Volf also got Kircher's early description of Cerknica Lake and Volf was therefore certainly one of our early admirers of the Karst phenomena. Ferrante's book was especially useful for the Prince Janez Vajkard, because he happened to be the very first systematic researcher of the subterranean world of Postojna Cave which was a part of his manor Postojna.

Janez bought Pazin (June 18, 1665) and together with his brother Volf also Belaj and Paz (1666). Nearby Kršan was also Janez' property at now Croatian Istria and he incorporated Paz and Kršan into Pazin County.

After his political downfall the recently widowed Prince Janez Vajkard with his seven children went to his County Wels and somewhat later emperor eventually permitted Janez' return to his native Carniola. To forget the reversal of his fortune Janez amused himself with hunting and scientific studies of the Karst. Few months before his December 1669 political debacle he bought the Karst Inner Carniola manors of Snežnik and Lož from the Prince Janez Anton Eggenberg on July 3, 1669. Janez also took the possession of Postojna manor with the famous cave included.

The prince Janez Vajkard certainly knew a lot about Postojna Cave even before he bought it. Philippus Cluverius (Cluverij, * 1580 Danzig; † 1622) described Postojna Cave in his posthumous work as »a big Cave with rustling river at the hollow hill near Ljubljana«. That and other Cluverius' works were well known in Carniola because they were selling as much as five Cluverius' books in Ljubljana just after Janez' death (Mayr 1678, 71–72). Humanist Cluverius became famous with his geographical research of the Antique and Near East. After the long travels through Germany, Italy, France, and England he lectured at the University of Leyden. Shortly after Cluverius' death Otto Guericke studied in Leyden. Three decades later Guericke collaborated with the Prince Janez Vajkard Auersperg on vacuum experiments and they probably exchanged their opinions of the vacuum role at Cluverius' like hollow hills and siphons under Javornik which occupied later Valvasor's Cerknica lake description.

The Postojna Cave was already widely visited at those baroque times and subterranean flow of the Pivka River was researched »at a distance of a whole mile«. Therefore curious Prince Janez Vajkard »of gentle memory« undertook his own research as a new lord of the manor Postojna. Soon after Volf's death Janez hired one of his bondmen for the subterranean river research under the one foot thick Postojna Cave natural bridge. The bondman was inured fisherman carrying with him a fishing net because his thrifty master Janez wanted to prove the surmises about the subterranean animals he had read about at Imperato's and other books from Volf's collection which he recently inherited. The collaborators tied the bondman to the rope and let him slip slowly by the cliff until he reached the water level. His helpers and fellow bondmen at the open chattered a little bit too much and did not hurry enough to return a poor researcher to the open air again. They were certainly quite amused when he after all joined them at the bridge carrying at his net a luce, carp, and bleak. Those fishes were not especially thick, but, sorry to say, pretty skinny. But they looked like ordinary ones and that was the information the Prince was searching for.

The prince Janez Vajkard was very satisfied anyway and wished to repeat the experiment. Therefore he offered the same bondman a whole crown for his efforts again. But obstinate farmer did not want to go to the cave depth once more even if the Prince offered him a whole manor of Postojna. He also refused to share any useful information: "I would not tell what I saw or hear at the depth; and I would even not confess why I don't want to descend again!" He was so persuasive that the Prince was unable to force him nor with a word nor with a sword. Even worse: the Prince had to abandon the further research because certainly there were no more volunteers. Everybody believed that there was something timid waiting just for him at the deep bottom. At that way one of the very first modern systematic Carniolan experiments came to its ill-humoured end. In 1679, a year and a half after Prince Janez Vajkard Auersperg's death, Janez Vajkard Valvasor found the aged cave-fisherman and tried to gain some information about his famous descent into the cave (Reisp 1983, 144). But even this time the bondsman did not want to tell any practicable details about his subterranean research, certainly among the first planned ones in this part of the world. From his behavior Valvasor concluded that the bondsman obliviously met some kind of monster at the dark cave which scarred him to his guts.

At that way or another Prince Janez Vajkard Auersperg proved Imperato's hypotheses even if Janez never published his own research in print. He lived in different time and social conditions when the high nobility was quite satisfied to share their knowledge at oral or manuscript form leaving the publications to the people of lower classes. Even without the publications of his own the Prince Janez Vajkard was the most influential promoter of the early new scientific ideas at Central Europe. In 1654 he became a patron of the very first German translation of the English pioneer of the new way of experimenting Francis Bacon Lord Verulam.

ATHANASIUS KIRCHER
(* 1601 Geisa; † 1680 Rome)

Volf was certainly an admirer of Tommasso Buoni's work and therefore bought two Bouni's books about the cosmography. At the first volume a member of the Roman Academy Buoni wrote about the angels, subterranean worlds, beauty, circumstances on Heaven and Earth, virtues, light, and animals. His treatise on the subterranean worlds was therefore almost the only scientific part of the book. At the second part he discussed the human virtues. He also wrote many librettos and is considered to be the author of some funny stories of the invented »*Compagnia della lesina*« which were republished several times during the 17th century.

Buoni's native Lucca attracted the Jesuit Kircher strong enough to write a book about it. Among the many books Kircher wrote just the one about Lucca remained unpublished because of to many errors even for Kircher's publishers. Valvasor owned almost all Kircher books, but Valvasor's paragon Volf also had many of them. In fact, Volf collected more than a half of all Kircher publications. Several of them discussed the Karst and subterranean phenomena. In 1658 Volf's librarian Schönleben wrote Volf's exlibris into Kircher's *Iter Extaticum II* also known as *Structura globis terrestris*. Kircher discussed there the very first useful description of the changing level of the Cerknica Lake, published eight years before

the famous Kircher's *Mundus subterraneus* which Volf certainly also had. It's a pity that Kircher did not see our Cerknica Lake with his own eyes but used the descriptions and letters of other visitors. Kircher also wrote about the interior of Earth, volcano, winds, and waters. He explained the structure of the Earth, fossils, minerals, and oceans. Among the first Kircher published the list of earthquakes and tried to find their causes. Volf's interest in earthquakes is also seen in his acquisition of Travagini's book and Kircher's *Diatribe* (1661) in which Schönleben wrote »ex dono Authoris« in 1663. *»Ex dono Authoris«* certainly did not mean that Kircher himself visited Volf in Ljubljana.

In *Diatribe* Kircher described many unusual objects at the sky just before the eruption of Vesuvius between August 16, 1660 and October 15, 1660. Kircher described similar events that took place in the years 363, 419, 958, and 1550. By the books Kircher personally donated to Volf we can judge that their mutual personal connections lasted at least between the years 1658 and 1663. During that time Kircher gave at least three books to Volf

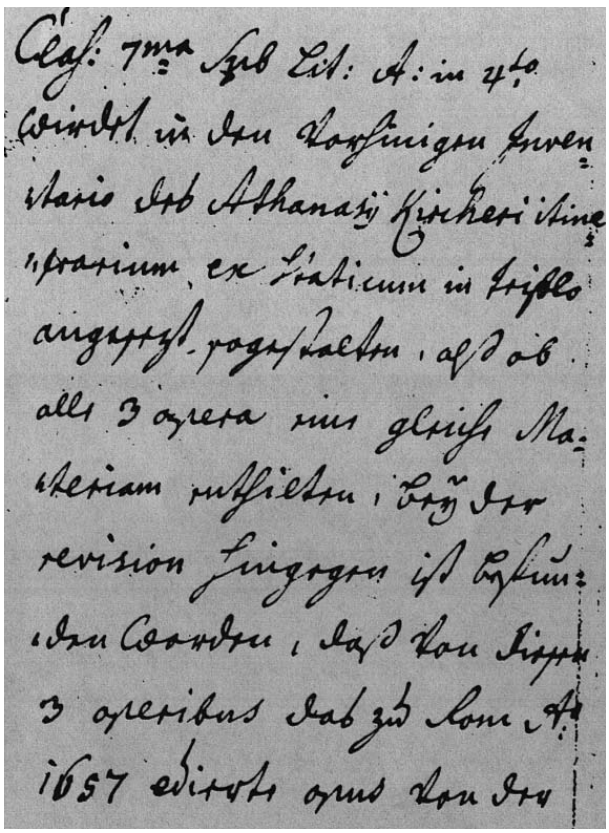

Fig. 5: Long description of Kircher's Iter extaticum II (1657) at the catalogue of Volf's books in 1668 according to the copy made in 1762 (HHStA FAA, 327).

Sl. 5: Daljši zapis o Kircherjevem Iter extaticum II (1657) v katalogu Volfovih knjig iz leta 1668 po prepisu iz leta 1762 (HHStA FAA, 327).

and certainly judged that kind of gift as a good business stroke which would help his books to sell better because of Volf's reputation and high official post.

FRANCISCO TRAVAGINI
(Travagino, Travaginus, * 1613 Dubrovnik; † after 1688 Venice)

The Venice physician and merchant Travagini described the Dubrovnik (April 6, 1667) earthquake two years after the tragedy. He dedicated his work to the otherwise unknown Venetian Habert Mammor in April 1669 (Travagini 1669, unpaged dedication IV, 19). At the title Travagini even separately stated the importance of the Copernicus »invention« of the daily rotation of Earth which proved to be very important for the Travagini's theory of earthquakes. Travagini stated that the daily rotation of Earth causes the pressures in unsteady subterranean.

Travagini was pretty popular at Ljubljana and besides Volf's acquisition Mayr also offered Travagini's book to Ljubljanians in 1678. Volf's exemplar of Travagini's book was bound with the older Bernegger's Latin translation of the very first Galileo's published work about the use of geometric and military "compass" (1612). The instrument later became an ancestor of the logarithmic and mechanical computing tools.

In 1679 Petreus summarized Travagini's works about the medicine and Dubrovnik earthquake, but Volf didn't buy Petreus' work. Travagini's book (1669) has Volf's bookplate: *»Exlibris… Wolfgangi Engelberti S:R:J: Comitis ab Auersperge Ducatus Carniolae Capitanei Catalogo inscriptus«.* The book has the supposed Radics's bookplate at the inner side of the front cover with a coat of arms and heading *»Fuerstlich Auerspergische Fideicommisionbibliothek zu Laybach«.* The geographer and publicist Peter Pavel von Radics from Postojna was the last Auersperg's Ljubljanian Librarian.

The bounding of Travagini's book with the Galileo's one was not mentioned at the catalogue of 1668/1762, but it's stated at the selling catalogue (HHStA FAA; Sotheby's 1982, 46). Probably they were not bound together before 1762.

Travagini became famous with his geometrical model of the traveling waves of lateral side vibrations between the epicenter of the earthquake and the point at the surface or between one and another point at the surface. He described the spreading of Dubrovnik earthquake from the South Adriatic to Venice and Naples (Travagini 1669, 11). Travagini considerably influenced later Robert Mallet's (* 3. 6. 1810 Dublin; † 1881) theory and as the very first described the waves without long-distance moving of the Earth mass. He verified his theory at the waves of Venice canals during the Dubrovnik earthquake. Near the canals he offered jet another useful illustration

Volf's exlibris	*Publication*	*Title and Place of Publication*	*HHStA, FAA page, library class; number in Sotheby's catalogue*
1655	1641	*Artis Magnetica. Rome*	327, Mathematics; 209
1658	1646	*Ars Magna lucis.* Rome	-; -
	1650	*Musurgia Universalis.* 1-2, Rome	397, Music; 211, 2: 314
	1650	*Musurgia Universalis.* 1st part, Rome	397, Music; 212
	1650	*Musurgia Universalis*. 2nd part, Rome	397, Music; 212
	1652, 1654	*Oedipus Aegyptiacus.* Rome	
1658	1656	*Itinerarium.* Rome (Donum Authoris)	329, Mathematics; 204
	1656	*Structura globis Coelestis (Iter Extaticum I).* Rome (duple)	327, Mathematics; 204, 205
1658	1657	*Structura globis terrestris (Iter Extaticum II).* Rome	327, Mathematics; 206, 207
	1658	*Scrutinum physico medicum.* Rome	315 Medicine; 218
1663	1661	*Diatribe di prodigiosis.* Rome (Donum Authoris)	233, Church History; 203
	1663	*Polygraphia*. Rome (Donum Authoris)	-; 217
	1667	*Historia Chinensis.* Amsterdam	244, Profane History; 202
	1667	*Regnum natura magneticum.* Rome	337 Philosophy; 210
	1669	*Ars Magna sciendi seu combinatorica.* Amsterdam	369, Linguistic; 201
	1671	*Descriptio Latium veteris et nova.* Amsterdam	244, Profane History; 208

Table 2: Kircher's books in Volf's library

of the oscillation with a vertically oriented beats of the hammer at the surface of Earth, which causes side waves (Travagini 1669, 17). At that way he joined the Venetian lagoon experience with a domestic smithy to present his own ideas to the reader as clear as possible. He compared the earthquake waves with the water waves and also with the pendulum oscillations (Travagini 1669, 26).

Travagini found that the same earthquake causes three different mixtures of the sequenced moves and side or inclined vibrations. At some distances from the source of the motion the sequence of beats could be stronger than the side vibrations. The succession of motions has a limited reach but the side vibrations could transverse a long distance. That enabled the vibrations of the Dubrovnik area earthquake to travel as far as Venice, where Travagini observed motion of the church chandeliers and the water fluctuations at canals.

Travagini imagined the Earth interior composed of sulfur, nitrogen, and water to make the spreading of the waves possible. At the same time he believed at the exhalations of fire and fragrances that were supposed to spread from the Dubrovnik epicenter to the other places (Travagini 1669, 9).

On December 22, 1666 Travagini of Dubrovnik began to mail letters to the secretary of the London Royal Society Oldenburg. Montagu brought the first Travagini's letter to London on April 2, 1667 together with the Travagini's message for the recently passed Kenelm Digby. Oldenburg answered from London to Venice on May 15, 1667. He praised Travagini's enthusiasm for experiments and offered him his own *Philosophical Transactions* of the London Royal Society asking Travagini to help him at the sales in Italy (Oldenburg 1966, 3, 303). Mayr offered the same Oldenburg's Philosophical Transactions to his Ljubljanian customers a decade before Travagini's death.

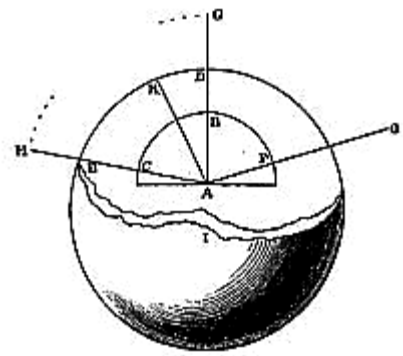

Fig. 6: Travagini's model of the Earth used to describe the spreading of earthquake oscillations.

Sl. 6: Travaginijev model Zemlje za širjenje potresnih nihanj.

Oldenburg certainly made some money with Philosophical Transactions sales.

Oldenburg highly praised Travagini's experimental philosophy, and on May 1, 1668 Taravagini reported about the research of Riccioli, Kircher and others in Italy (Boas Hall 2002, 86; Oldenburg 1967, 4, 328). At the same time Travagini exchanged the letters with Marcello Malpighi about medicine. With the Secretary Oldenburg's support Travagini became a Fellow of the London Royal Society on February 10, 1676 (Oldenburg 1986, 12, 6). A decade later (December 14, 1687) Valvasor was elected too. Oldenburg knew Travagini's *Synopseos Novae* about the acids and alkalis (Thorndike 8, 216). Oldenburg kept Travagini's research of the Dubrovnik earthquake at his library. As a Venice physician Travagini also occupied himself with profitable trade. He was even supposed to accomplish two successful transmutations of the quicksilver to pure silver with a help of herbal extracts. But he was unsuccessful at other fifty experiments of that kind. In October 1675 Boyle examined the silver acquired at Traviagini's way and mailed to Oldenburg, but Boyle's opinion was the not quite favorable (Oldenburg 1971, 8, 62; Oldenburg 1977, 11, 231, 292, 355-356).

JAKOB JOANNES WENCESLAUS DOBRZENSKY DE NIGRO PONTE

(Jakub Jan Vaclav (Wenčeslav) iz Černeho Mostu (Schwartzbrug), * 1623; † 1697).

Volf certainly followed the alchemistic quarrels between his three years older fellow Carniolan Janez Friderik Rain (* 1613 Strmol; † after 1686) and Dobrzensky. Therefore Volf bought the book about hydro technique which Dobrzensky published already during his studies at Ferrara, after he spent some time as a classmate of Volf's friend and first librarian Schönleben at Padua. It's hard to decide which side Volf supported during the quarrel as he certainly knew both protagonists in person.

Dobrzensky was a descendant of the famous Prague physician family, but his own father was an administrator at the salt storehouse. Dobrzensky studied at the Italian universities of Padua, Ferrara, Bologna, and Modena as many Carniolans did at the same time. Only Kircher's friend Marcus Marci was able to arrange Dobrzensky's return back to Prague where he finished his studies in 1663. Dobrzensky worked for some time at Karlovi Vari and began to lecture at the University of Prague only in 1664. At the year of Marci's death Dobrzensky became an assistant professor. In 1682 he was promoted to the ordinary professorship and next year he got a chair for practical medicine (Svobodný 1998, 79; Štoll 1998, 132; Minařik 2000, 351). At the years 1670 and 1685 Dobrzensky was a rector of the Prague University (Šolcová 1998, 194). He exchanged the letters with Kircher and most of all admired Marcus Marci (Lienkauf 1993, 62; Marek 1968, 130).

Dobrzensky cited Riccioli, Copernicus, and Galileo's opinions about the influence of Earth rotation on the fountains. He even found useful Helmont's hypotheses that there is thousand times more water in the subterranean than in all oceans put together. Dobrzensky tried to prove that quicksilver contained water which filled the supposed vacuum during Torricelli's experiment. He went even further and claimed that his own friend Kircher was the real inventor of barometer (Thorndike 1958, 7, 584-585, 8, 202-203).

JOHANN JOACHIM BECHER

(* 1635 Speyer; † 1682 London)

Becher was for a while the most influential Viennese authority on the natural history and economy. Volf bought three Becher's works, and Mayr in 1678 offered another three, among them two Becher's Physics of Subterranean (1669). Primary Mayr listed a second part of Becher's title *Physica Subterranea Libri duo,* and on the second occasion the first part of the title *Actorum Laboratorii Chymici Monacensis.* At that book Becher published the iatrochemical research at the style of Paracelsus or Helmont. In fact Becher refused Paracelsius' school with sulfur as the principle of all inflammable mater including metals. Becher preferred *terra pingus* which Stahl half of a century later rechristened to the phlogiston (Pavšek-Baždar 1994, 12). Four years after Kircher's *Mundi Subterranei* (1657) Becher tried to describe subterranean worlds on his own terms in *Actorum Laboratorii Chymici Monacensis* (Thorndike 1958, 7, 578).

As the personal tutor of Robert Boyle's nephew Jones during his European "grand tour" Oldenburg paid a visit to the still young but already famous Mainz physician Becher in 1658 (Boas Hall 2002, 34, 36). In 1666 Becher became a lecturer of medicine in Mainz and the personal physician of Archbishop and Prince-Elector Johann Philipp von Schönborn (* 1605; † 1673). At that function he met the Jesuit Gaspar Schott from the nearby Würzburg, who was Kircher's best student. Schott dedicated his book (1664) to Schhönborn and Volf certainly did not hesitate to acquire the item.

In 1666 Becher also became the commercial adviser at Vienna and that high position certainly helped to popularize his works at our lands. After the political downfall of the Prime minister Prince Janez Volfgang Auersperg in December 1669 Becher enjoyed the political support of Count Albrecht Zinzendorf (* 1619; † 1683), the son of the Johann Joachim von Zinzendorf (* 1570; † 1626). The Count Albrecht Zinzendorf became a new prime minister of the emperor Leopold I and the member of the secret

council (Sienell 2001, 173). The Emperor sent Becher to Holland where Becher adopted the mercantilism ideas. Stahl later used Becher's theories to develop the doctrine of the phlogiston which influenced all research of heat phenomena until Lavoisier. In 1668 with reprint six years later Becher published his didactic studies (Lind 1992, 369) and Volf hurried to get as much as three exemplars of that masterpiece. In January 1680 Becher described his accurate clock to the Royal Society of London. Becher even tried to take over Galileo and Huygens' priority claiming that he himself used the very first pendulum for the time measurements. Ljubljanians bought Becher's London work on clocks bound with the older Boyle's experiments, Sturm's Altdorf letter about the hydrostatics of air mailed to Henry Moore, Peter Mousenk's edition of Joannis Danielis, Joannes Alfonz Borelli and Lyon issue of Fabri's book about the physics of the local motion (1646). Besides the inventor of the telescope Cornelius Drebbel Becher mentioned many discoveries of the Jesuits Riccioli, Kircher, Schott, and Sturm. At the end Becher made some propaganda for his publications and listed them sorted by the field of research (Becher 1680, 3, 15, 17, 22).

CONCLUSION

Volf's library was among the best of his time. He and his brother Janez were personally interested in the karst phenomena as the patriotic Carniolian nobles. Janez even organized some first rate research at Postojna Cave.

The enviable education of Carniolan high nobility and their interest in the local Carniolan curiosity was the base for Valvasor and even later Hacquet and Gruber's work. With a close look at Volf's rich library the success of continuators of his endeavours wasn't any real surprise.

ACKNOWLEDGEMENTS

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KNJIGE O KRASU V TURJAŠKI »KNEŽJI« KNJIŽNICI V LJUBLJANI

POVZETEK

Opisane so knjige o krasu iz nekdanje ljubljanske turjaške knežje knjižnice. Pri njihovem iskanju smo si pomagali z rokopisnim katalogom iz leta 1662 prepisanem leta 1762 in s prodajnimi katalogi iz let 1982-1983.

Posebej so izpostavljena znanstvena nagnjenja in usmeritve prvih lastnikov knjig, predvsem turjaškega grofa Volfa Engelberta in njegovega brata kneza Janeza Vajkarda. Podrobno je raziskan pomen nekaterih njunih nabav. Knjižnica služi kot osnova za razmišljanje o poznavanju krasa pri Turjačanih, ki so bili lastniki več graščin na krasu, med drugim postojnskega gradu. Podane so primerjave z drugimi knjižnicami 17. stoletja v cesarstvu in drugod po Evropi.

V baročni dobi Volfa Engelberta Turjaškega znanost o Krasu še ni bila rojena v sodobnem pomenu, saj so šele stoletje pozneje kranjski raziskovalci na čelu s Hacquetom in Gruberjem postavili temeljna načela krasoslovja. Kljub temu je Volf imel več zanimivih in pomembnih raziskav o krasu, ki so jih objavili Aldrovandi, Ferrante Imperato, Johann Joachim Becher, Tommasso Buoni, Jakob Joannes Wenceslaus Dobrzensky de Nigro Ponte in Athanasius Kircher. Volfov brat Janez pa se je tudi sam aktivno lotil raziskovanja krasa, še posebej v podzemlju Postojnske jame.

COBISS: 1.01

KARST RESEARCH IN SERBIA BEFORE THE TIME OF JOVAN CVIJIĆ

RAZISKAVE KRASA V SRBIJI PRED JOVANOM CVIJIĆEM

Jelena ĆALIĆ[1]

Abstract UDC 551.44(497.11)(091)"18/19"

Jelena Ćalić: Karst research in Serbia before the time of Jovan Cvijić

Although contributions by Jovan Cvijić are the most significant karstological work in the history of science in Serbia, the researchers of Serbian karst before the time of Cvijić are worth mentioning as well. Their karstological notes are usually parts of much more extensive works in the form of travel-records or landscape monographs. Most notes are related to caves, with only scarce mentioning of karst surface features. The descriptive character of the texts is dominant, although there are also some general remarks on hydrological functioning of karst (ponor-spring connections, role of water in formation of speleothem, etc.). Several authors can be singled out: foreign travellers and scientists Otto von Pirch, Ami Boué and Felix Kanitz, while among the Serbian authors, it is necessary to mention Milan Đ. Milićević, Jovan Žujović and Cvijić's teacher Vladimir Karić. All of them featured as an introduction to the scientific karstological work which followed at the end of the 19th and the beginning of the 20th century.

Key words: history of karstology, 19th century, pre-Cvijić, Serbia.

Izvleček UDK 551.44(497.11)(091)"18/19"

Jelena Ćalić: Raziskave krasa v Srbiji pred Jovanom Cvijićem

Čeprav je Cvijićev prispevek h krasoslovju najpomembnejši v zgodovini znanosti v Srbiji, so raziskovalci srbskega krasa pred Cvijićevim časom tudi vredni omembe. Njihovi zapisi o krasu so običajno vključeni v veliko obsežnejša dela v obliki potopisov ali pokrajinskih monografij. Večina the omemb se nanaša na jame z zelo skopimi omembami kraških površinskih oblik. V the besedilih prevladuje opisni značaj, čeprav je tudi nekaj omemb glede hidrološkega delovanja krasa (zveze med ponori in izviri, vloga vode pri nastajanju kapnikov, itd.). Nekaj avtorjev je treba posebej poudariti: tuje popotnike in znanstvenike, kot so Otto von Pirch, Ami Boué in Felix Kanitz, medtem ko so med srbskimi avtorji posebej vredni omembe Milan Đ. Milićević, Jovan Žujović in Cvijićev učitelj Vladimir Karić. Vsi navedeni so predhodniki znanstvenega krasoslovnega dela, ki se je pričelo konec 19. in v začetku 20. stoletja.

Ključne besede: zgodovina krasoslovja, 19. stoletje, čas pred Cvijićem, Srbija.

INTRODUCTION

Whenever karst research in Serbia is mentioned, the first association is always Jovan Cvijić (1865-1927), who is worldwide considered a founder of scientific karstology thanks to his major work "Das Karstphänomen" (1893). The year 1887 can be taken as a start of Cvijić's explorations of Serbian karst: he published his first scientific paper, dealing with geographical terminology (Cvijić 1887), in which karst terms were presented to a significant extent. In 1889 he published his first paper related particularly to karst relief in Eastern Serbia (Cvijić 1889).

Speaking about any geographical research in Serbia before the time of Cvijić, it is necessary to point to some historical circumstances. From 1459 to 1878, Serbia was constantly under the rigid government of the Ottoman empire. The life of ordinary people was marked with utter poverty and permanent assaults by the occupation army,

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while the educational system was practically forbidden. There were no schools or universities, and consequently, no conditions for any scientific work. Scarce records on geographical and geological characteristics were made by foreign travellers, like Otto von Pirch (1830) and Ami Boué (1840), while the first Serbian travel-records appeared also in the first half of the 19th century, when Serbia started to obtain some elements of autonomy. These were the travel records by the linguist and ethnologist Vuk Karadžić (1826) and the writer Joakim Vujić (travels from 1826, published in Serbia in 1901 and 1902). It must be stressed that pre-Cvijić notes on Serbian karst were mostly of descriptive character, just with some fragments of general conclusions on functioning of karst, but without the complex elements of scientific studies. Most of the descriptions were related to caves, due to the fact that extensive karst surface phenomena occur only on remote locations that were very scarcely populated, and generally out of the routes of travellers.

OVERVIEW OF MOST SIGNIFICANT CONTRIBUTIONS

Vuk Karadžić (1826) made a brief mention of Turčinovac Cave in his descriptions of monasteries in the gorge of the Zapadna Morava River. That is the oldest written reference about any cave in Serbia. A number of monasteries dating from 14th to 19th century were built in isolated gorges and caves, in order to be hidden from the Turks.

A more lengthy description of several caves was given by Vujić in his 1826 travel-records (1901, 1902). Vujić did not use the term "*pećina*", which is the usual Serbian word for "*cave*", but the words "*peščera*" and "*grota*". It is obvious from the descriptions that he did not enter any of these caves, but only made some observations at the entrances, with notations of local legends, and attributes like "horrifying", "frightful", "dark". Vujić mentioned the cave entrances in Gornjak gorge, the cave Ravanička Pećina, as well as the cave Petnička Pećina in western Serbia, in which he correctly noticed the intermittent character of the outflowing stream Banja.

A Prussian officer Otto Ferdinand von Pirch travelled through Serbia in the year 1829 and published a book about that in Berlin in 1830 (Serbian translation of this book was published in Belgrade in 1899). Apart from the caves in Gornjak gorge, and the cave Ravanička Pećina, he also mentioned the caves by the town of Golubac (Pećine Golubačke Mušice), at the entrance to the Danube gorge. Pirch's descriptions are much more realistic and objective than those of Vujić, containing also some details about perceptions and/or usage of caves by the local population (e.g. during the winter, shepherds lodged the goats in caves; monks from Ravanica monastery went with torches into the cave Ravanička Pećina for 3-4 hours; etc.).

Probably the best pre-Cvijić notes on some caves in Serbia were given by the French/Austrian geologist Ami Boué (1840, 1891), during his geological explorations of so-called "European Turkey". Like Pirch, Boué visited the caves in the Gornjak gorge, the cave Ravanička Pećina and the caves in the Danube gorge, but also the ice-cave Ledenica on Mt.Rtanj, where he measured the air temperature at the bottom. As he visited a great number of caves on the whole Balkan peninsula, he made some conclusions about their genesis: "Most of the great caves are nothing else but remnants of old underground water courses, while more shallow caves are caused by partial decomposition of rocks, with an influence of bedding". Boué also noticed occurences of karst surface relief: "Rocky surfaces full of dolines, like in Lower Carinthia, occur in the area of Turkish Croatia; *in the surroundings of Valjevo in Serbia*; between Sijatista and Kožan in Macedonia…". There is also an interesting remark about relation between surface and underground morphology: "In Cretaceous limestones, natural shafts are also frequent, although they are rarely so nicely characterized as in the case of Ledenica, in the woods on the southern slopes of Mt. Rtanj. Dolines or "kombi", that mainly occur on limestone plateaus, are nothing else but similar shafts or fissures, through which waters sank for a long time, until finally breakdowns occurred due to prolonged erosion." (Boué 1891).

Another foreign traveller who made a lot of notes on karst forms in Serbia was Felix Kanitz. He made a number of travels through Serbia during more than 30 years (from 1856 to 1899), searching mainly for archeological remains of Greek and Roman civilizations. However, his studies were much more than that: in two large volumes of travel-records (published in 1909), he made precious and wise observations of natural and social characteristics of 19th century Serbia. Kanitz's descriptions of natural phenomena abound in interesting details and comparisons, and there is a noticeable tendency towards scientific, problem-solving approach. He visited many more caves than the previous travellers, and paid considerable attention to surface karst morphology as well. In the cave

Prekonoška Pećina, he visited even the most distant passages and chambers: "The Third chamber, which can be entered only using the rope, contains beautiful cave decoration, that reminds of Adelsberg, and of a coupola building with countless pillars, altars, chandeliers, etc. In side passages there are conspicuously big stalactites as well, and in all passages there are remnants of extinct animal species." Writing about Mt.Kučaj, Kanitz observed: "Its high plateaus, that incessantly extend towards the east, are rich in small streams, that usually end in funnel-shaped ponors, and through deep bottoms of dolines, sink into lower permeable layers of limestone. (…) A bit further towards the north-east, surrounded by 40 smaller dolines, there is a 250 m long doline Brezovica, with steeply cut edges and a 120 m long stream that sinks into a deep abyss."

Felix Kanitz

A famous Serbian biologist Josif Pančić, during his fieldwork in 1856 and later on, visited several caves and paid particular attention to paleontological remains of extinct animals (cit. Petrović 1988). S. Mačaj (1892) gave the first written description of Toplik Cave (south of the town of Zaječar in Eastern Serbia), which is the outflow of thermal water. It is important to point to the paper of J. Mišković (1872), in which there are valuable observations about small karst areas in central Serbia (Šumadija region, around Mt.Rudnik), where limestones are rather rare. Writing about the cave Vodena Pećina, he stresses the importance of geological composition, and notices cave biota as well: "Vodena Pećina is the real and the main spring of Čemernica River. (…) In the cave, there are lots of bats. It is dark and one cannot make even 10 steps without the light. The rocks are of lime formation, as well as all the surroundings, and that is why it is characterized by numerous caves…". Regarding the karst spring of Ljig River in the village Ba, in the same region, Mišković wisely notices the difference between the outflow from Vodena Pećina (modern karstological term would be 'gravitational' outflow) and from the Ljig spring (siphonal uprising): "The spring of Ljig, as well as that of Čemernica, emerges from lime formation of rocks, from a cave (…). However, this spring varies from that of Čemernica, because here the water 'boils', comes from below… when something is dropped on that place, it sinks very deep, so it is obvious that this is a great abbyss, and that the water emerges from below (…). Sometimes the water is high, and then it is murky, carrying red soil. That is why it is believed that its head is in Dobro Polje, because such soil can be found there." (Mišković 1872).

Milan Đ. Milićević was a well-known Serbian intellectual from the second half of the 19th century. His major work "Kneževina Srbija" ("Principality of Serbia") was published in 1876, just two years prior to Serbia's gaining of independence. This is the work of historical and geographical character, with abundance of valuable facts and data, although his descriptions sometimes have a kind of "romantic" approach, like in the case of the cave Prekonoška Pećina: "It is only the dripping water that interrupts, but very softly, this quiet silence, deep underground. And it is the water that makes these miracles that you admire in the cave". Apart from the descriptions of significant caves like Petnička Pećina, Prekonoška Pećina, Zlotska Pećina (mostly the same ones as the previously mentioned authors), Milićević pays particular attention to surface morphology, underground hydrological connections, and general functioning of karst (although he does not use that term). "People who live close to Mt.Rtanj, and who often climb its highest peak Šiljak, have noticed that sometimes some dolines, some holes plunge down on this mountain. Half joking, and half seriously, they say that Rtanj is dissolving, and that, by acting in that manner, it can lower so much that it will become like some usual hill". One of the interesting karst phenomena, a deep siphonal spring of the Mlava River in the village of Žagubica in Eastern Serbia, occupied the attention of Milićević as well: "It cannot be said for sure where the water of this spring comes from; but people from Žagubica have noticed that this spring always becomes muddy when there is a heavy rain on Mt. Beljanica (south from Homolje). However, when it rains on Crni Vrh, Mlava flows as usually". Apart from the spring Banja, which flows out of the cave Petnička Pećina, Milićević describes one more intermittent spring – Potajnica in the region of Zvižd in Eastern Serbia. Potajnica is not only a toponyme, but also a Serbian term for intermittent spring. "Potajnica in Zvižd, half an hour below Kruševica, on the right bank of the Pek River. Potajnica is situated 5 *hvats*[1] above the Pek water surface, and 10 hvats away from the Pek. It is in lime rocks. People say that it fills with water 5, 6 or 10 times a day, and then empties itself again; water sinks somewhere between the rocks, and when that happens, one can hear some noise, like a drum, like a roar of stones, or a blow of wind". When describing probably the most extensive karst area in Eastern Serbia, the section from the Danube to Mt.Rtanj, Milićević draws some conclusions: "It happens that very strong and abundant

[1] Hvat, an old measure for length. 1 hvat = 6 feet

streams sink into some doline, or a heavy rain rushes into some echoing hole ("zvečara"), and it is considered that this water resurges afterwards, far away, as a new spring. This can also be the case of the springs of Mlava and Krupaja" (Milićević 1876).

One of the most important persons for the whole history of karst research in Serbia is definitely Vladimir Karić. His direct influence is reflected through a capital book "Serbia", published in 1887, with detailed descriptions of natural (and other) characteristics of Serbia, including karst phenomena. Karić's indirect influence on karst research in Serbia and on karstology as a scientific discipline is the fact that he was a secondary-school teacher of Jovan Cvijić, and actually the one who persuaded Cvijić to enroll the studies of geography.

Entrance to the cave Dubočka Pećina (sketch by Vladimir Karić, 1887)

Vladimir Karić had a tendency of introducing new terms for some karst forms into the Serbian scientific literature. One of those examples originated from his description of the cave Petnička Pećina: "When one enters inside, he finds himself in a big chamber, which is relatively bright, thanks to two natural rounded holes on the cave ceiling, decorated with green ivy, that are popularly called *vigled*." *Vigled* means 'daylight hole' or 'cave ceiling window', and that term is still in regular use in Serbian karstological literature.

In his extensive chapter on the cave Prekonoška Pećina, as well as in descriptions of some other caves, he uses the term "*kapnik*"[2] for calcite speleothem (*kapnik* is presently used only in Slovenian language, not in Serbian): "After entering the cave, there is immediately the brightness of snow-white pendants[2] consisting of *kapnik* stone, that hang from the ceiling, or grow from the floor, or the two are finally connected to each other and resemble marble columns. The floor is white as well, because it is also coated in tufa *kapnik*. Going a bit farther, pendants are no longer present, the floor becomes clayey, while the high ceiling is black of numerous bats, that have hidden there and have attached to the rock. Below the clay, there are bones of cave bears, and maybe also of some other extinct animals, as well as some remnants of clay dishes, formerly used by men – previous inhabitant of these caves". In the cave Zlotska Pećina (also called Lazareva), there were also observations of speleothem: "At the beginning, only dripping of water can be heard. Only somewhere, pendants of *kapnik* rock can be seen, created by water, little by little through the centuries, seeping through lime cave ceilings and dripping on the floor".

Within Karić's book "Serbia", there is a chapter related to geological composition, written by the founder of Serbian geology, Jovan Žujović. In this chapter (as well as in some of his papers, like the one published in 1889), Žujović gives his opinions on cave genesis and functioning of karst: "In limestone areas, the water carved numerous, big, often very branching caves, in which sometimes the remains of ancient animals and men can be found. In this respect, the most interesting caves are Zlotska, Prekonoška and Petnička. Water in these areas, captured in dolines, cannot flow across the surface, but descends through the fissures to the depth, where in the network of favourable conduits it collects into underground rivers that emerge to surface as springs, with huge amounts of water".

[2] The word used in the original text is *ledenica*, meaning "ice pendant", but it did not remain as a term, because it stands for a genetically different feature.

CONCLUSION

It can be concluded that the observations of Vladimir Karić, together with the geological comments of Jovan Žujović, represent the cross-section through the state of karst research in Serbia before the capital works of Jovan Cvijić. However, all the mentioned authors have contributed to a significant extent to the basic notions on Serbian karst, and play their role, as a historical background, in the scientific approaches which followed afterwards, in the 20th century.

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SHAFTS OF LIFE AND SHAFTS OF DEATH IN DINARIC KARST, POPOVO POLJE CASE (BOSNIA & HERZEGOVINA)

BREZNA ŽIVLJENJA IN BREZNA SMRTI NA DINARSKEM KRASU, PRIMER POPOVEGA POLJA (BOSNA IN HERCEGOVINA)

Ivo LUČIĆ[1]

Abstract UDC 551.44(497.5)

Ivo Lučić: Shafts of life and shafts of death in Dinaric karst, Popovo polje case (Bosnia & Hercegovina)

In literature, Popovo polje is considered as a distinctive phenomenon of Dinaric karst. It is situated in the south part of Dinaric karst, at the end of Trebišnjica watershed. Recorded within it are numerous other typical phenomena. Shafts, ponors and estavelle (all three are traditionally called jamas) played an important role in traditional life of people from Popovo polje. In the article, "jamas" are assessed based on whether they were a source of life and on the side of life or against it, i.e. were lethal for the lives of people of Popovo polje region. Included in the first category are shafts which were oasis of drinking water in summer time, shafts which were made suitable for fishing the endemic fish Popovo Minnows *(Delminichthys ghetaldii)* and shafts on top of which over 40 flour mills were built. On the other side, shafts of death are natural shafts which were used as mass graves in the World War II. Most literature deals precisely with these. Shafts were subject of comprehensive research of Popovo polje for the needs of Trebišnjica Hydro-system Project, and extremely important and interesting bio-speleological endeavors, but those aspects remained outside the perception of general public of Popovo polje.

Key words: Karst landscape, Dinaric Karst, Bosnia & Herzegovina, Herzegovina, Popovo polje, shafts, fishing, mills, mass graves.

Izvleček UDK 551.44(497.5)

Ivo Lučić: Brezna življenja in brezna smrti na Dinarskem krasu, primer Popovega polja (Bosna in Hercegovina)

V literaturi je Popovo polje omenjano kot ena izmed pomembnejših kraških oblik Dinarskega krasa. Leži v njegovem južnem delu, v skrajnem koncu porečja Trebišnjice. S polja so znani številni tipični kraški pojavi. Brezna, ponori in estavele (vse tri ljudje imenujejo jame) igrajo pomembno vlogo v vsakdanjem življenju ljudi s Popovega polja. V prispevku so lahko te jame vir življenja in so na strani življenja, lahko mu pa nasprotujejo, so smrtne za prebivalstvo območja Popovega polja. V prvo skupino sodijo brezna, ki so poleti kot oaza vir pitne vode; brezna, v katerih je mogoče loviti endemične ribe *Delminichthys ghetaldii;* brezna, vrh katerih je bilo zgrajeno preko 40 mlinov. Na drugi strani pa so brezna smrti naravna brezna, ki so jih med II. svetovno vojno uporabljali za množična grobišča. Veliko literature se ukvarja prav s tem. Brezna so bila predmet podrobnega raziskovanja ob raziskavah Popovega polja za potrebe projekta Hidrosistem Trebišnjica, pri čemer je prišlo do zanimivih in pomembnih speleobioloških odkritij, medtem ko je drugi vidik, brezna smrti, ostal v širših krogih nezapažen.

Ključne besede: kras, Dinarski kras, Bosna in Hercegovina, Hercegovina, Popovo polje, brezno, ribolov, mlin, množično grobišče.

POPOVO POLJE FEATURES

The karstologists (Groller 1889, Cvijić 1893, Katzer 1903, Richter 1905, Absolon 1916, Milojević 1938, Malez 1970, Milanović 1979, 2006, et. al.) describe Popovo polje as a typical karst phenomenon. It is located in the south part of Dinaric karst at the end of Trebišnjica river shed. Out of the seven karst poljes, it is the nearest to the seacoast surging its waters to the three different sides of the world. Annual average precipitation is 1750 mm per square meter of the river shed. The shad's altitude amplitude is around 2000 meters, while the altitude of the polje varies

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from 250 to 225 meters. Popovo polje is developed in the area of bare karst and it is an area with great geo-dynamics. Furthermore, its main features are high purity of carbonate rocks, with calcite mineral contents reaching even 99, 98 percent (Raić & Papež 1982).

There are different geographic features of the Popovo polje area. The basic idea most commonly includes the area of floods and with alluvial deposits surrounded with hilly frame, and this is the area between the villages Poljice and Hutovo. However, Popovo polje, sometimes, also includes the area encompassing the entire flat part of the Trebišnjica valley. Namely, going upstream Popovo polje in the southeast direction is Trebinjska šuma, i.e. the area between Poljice and Trebinje, which is different because its bottom is not covered with alluvium. In addition, there is also this historical name - Popovo, which, in addition to the polje, encompasses a part of karst hills between the west edge of Popovo polje and the border with the Republic of Croatia at this point getting only a couple of kilometers away from the Adriatic Sea. For purpose like this, it would be opportune to include some other villages to this area of Popovo polje that are located on its north edge, which were left out in the previous descriptions of Popovo polje, because they are quite close to Popovo polje and their inhabitants have had continuous and active relations with it.

Fig. 1. Lower, NW part of Popovo polje.

In addition to polje, there are many other kart phenomena: typical karst plains, karst hums (inselbergs, mogote), rivers, dry valleys, ponikvas, ponors, numerous caves and a number of smaller forms, such as: karrens, kamenicas, etc.

SHAFTS IN POPOVO POLJE

The exact number of caves in Popovo polje is not known because there is no registry of such features. The Trebišnjica Hydro-system Project, which was the platform for many field research operations between fifties and seventies of the 20th Century, created a registry of ponors and estavellas that are located in the Trebišnjica riverbed and in its close proximity. According to this registry, there are more than 240 ponors and ponors area in the riverbed, 50 of them with one or more openings being located in Popovo polje. According to our list, outside the Trebišnjica riverbed area, on the broader area of Popovo polje there are around one hundred of all kinds of hole where human can enter. Typologically, in Popovo, there are semi-caves, caves, potholes, ponors, diffuse ponors, alluvial ponors, estavellas, springs and oduhas. Oduha is the shaft located above the surface of the underground cannels that are used for drainage of Popovo polje, and sometimes, they strongly blow air.

Here, cave types are traditionally divided into large karrens (local called škrip), semi-caves, caves and shafts. The škrips are holes in rocks that are created from fractures and whose size varies from one to four meters. These type are often bigger in its lower part (Roglić 1974, 59). They are morphologically dominant in extreme karst areas called "ljuti" (karren karst) by local people. They served as shelters for shepherds and hunters, and often, a small domestic animal would find itself in one of these. After the Second World War, the defeated army members would hide themselves in the karrens (škrips) where they would often stay for months, even years. They were popularly called "škripari" (men from karrens). The inhabitants of Popovo polje simply called all estavellas and ponors – jama (Ćurčić 1915, 67). "Jamas" in the polje are divided by their hydrological function on those "guzzling" and those "guzzling and throwing up" water. Regardless of the size of their "mouth", their cave entrance or shaft entrance – they were called Jamas. (Ćurčić 1915, 67). That is how they called Crnulja ponor as well, which is located at the closing part of Popovo polje or Nova Baba near Strujići, Baba below Čvaljina and Gladulja near Zavala, in spite of the fact that they all have horizontal cave-shaped entrances. In the life of the locals, "jamas" were very important. Estavellas used to bring huge quantities of water to Popovo polje, causing Trebišnjica to flood - in addition to her own shed, when it used to produce even 1400 cubic meters per second in its peak season (Milanović 2006, 124). In a short period of time, this spacious Popovo polje would be completely flooded.

The floods mainly came in autumn, while crops were still not harvested, and they would last until springtime. As polje was the main source of food for a dozen of villages in its proximity, estavellas were observed with great attention.

SHAFTS OF LIFE

WATER SUPPLY

Until the 20th century, some "shafts" have served as water supply sources in extremely dry seasons. In summer time, all water-flows dry up; *kamenicas* used for cattle also become dry, as well as the local wells and the few springs, which made a good reason for the locals to seek water underground. Those were the shafts that were naturally accessible or some minor accessories were required to enter them and one of them was Srednja mninica mill below Ravno. They usually had weak lighting – a torch, maybe – and therefore, they had been often afraid of going down, which resulted in their exaggerating the dimensions of the underground channels.

Fig. 2 North-East slopes of Popovo polje (straight ahead and on right) are rounded by many fish shafts.

SHAFT WALL ENCLOSING

Estavellas that are located at the polje level used to be the places where floods would wash soil causing harm to the farmers. Therefore, the locals of Popovo used to enclose the shafts and grow bush around the openings to prevent "jamas from enlarging and taking away the fertile soil when swallowing the water" (Milošević 2004, 19). However, actions that are more complex used to be taken when dealing with so-called fish shafts.

FISH SHAFTS

For fishermen, estavellas used to be passages with high population of endemic fish called Popovo minnow that used to leave the underground in Autumn heading towards ground waters. These estavellas were called "fish jamas" (jama ribarica), while the fish used to be called – "jama fish" (riba jamarica) (Ćurčić 1915b). In summertime, Popovo minnow (*Delminichthys ghetaldii* Steindachner 1882 – syn. *Phoxinellus g.,* syn. *Paraphoxinus g,* Pisces, Cyprinidae) spend their days underground, while in the rain seasons, when Popovo polje becomes a huge lake, they live in ground waters. The taxonomic status of Popovo minnows changed several times. Based on modern molecular and morphological research, the status of Popovo minnows and similar fishes was organized in three genders. Popovo minnows was included in the newly established gender *Delminichthys*. (Freyhof et al. 2006) This Popovo minnows inhabits east Herzegovina, from Dabarsko polje, over Fatničko polje and Ljubomirsko polje (Bosnia and Herzegovina) to Ombla river along the coast of Dubrovnik (Croatia). Although the renaissance zoologist, U. Aldrovandi (1522-1605), was engaged in the morphology of this species, when the famous paintings «Gobize raguseus» was made (Grmek & Balabanić 2000, 171), there is not much known about Popovo minnow. Accordingly, the textbooks do not provide an analysis of the information given by the fishermen from Popovo polje saying that Popovo minnow were different by their color depending on the shaft from which they emerged. For those coming from the area of village Strujići, they say that the fish is blue along their

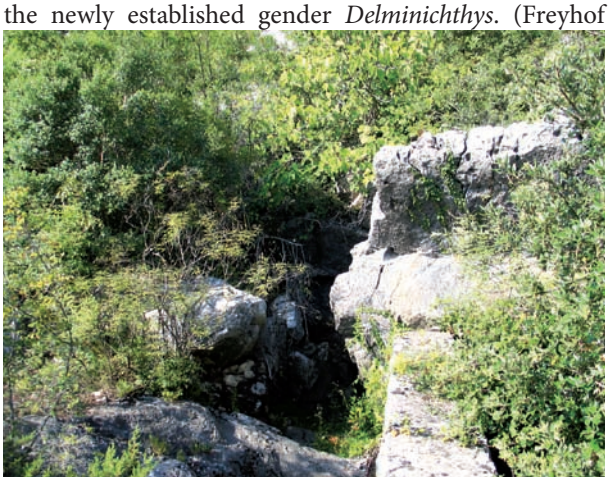

Fig. 3. Estavella Baba, wall adopted for traditionally type of fishing.

backs; those from Ratac – green; in Mneč and Kravari – palke, and from Pećina – the greenest. (Ćurčić 1915b, 71) They say also this: "As soon as the water starts coming back, every fish stays in her shaft, not to be left on dry land". Accordingly, every fish exclusively goes back to the estavella from which it came. Fish is thrown out only by those shafts that throwing up the water (Ćurčić 1915b, 70), i.e. that are thicker estavellas. While they are pretty rare on the left side of polje, on its right side it is even difficult to count them all. As an example, Ćurćić takes the area of the village Strujići in the middle of polje, listing 25 estavellas by their individual names "being only half an hour away from each other by foot".

They distinguish by the moments when fish emerges in them: in some of them, fish emerges with the first streams of water, while in some of them, it takes at 2-4 meters of water for fish to come, and one of them is Bender mlinica below the village of Velja Međa. Almost all estavellas are suitable for fishing. The shaft neck is walled in circles with stone blocks, and from the opening, on the ground, there used to be many canals that widen at their end. The shaft opening used to be closed with a huge stone and coil baskets were put in wide parts of canals. These baskets served as water filters used for fishing. Apart from these, smaller baskets were also put in some estavellas, where the water levels were usually lower.

The third way was fishing with nets. The nets were made of silk that was produced by breeding silkworm. «One who wishes his silk-worm come out earlier should wrap up the seeds in a small tissue » (Mićević 1952, 61), where the temperature was obviously suitable for the silkworms. Shafts produced different quantities of Popovo minnows: in Mnetač jama, once, the locals caught 40 quintals[1] of fish with a small basket whose capacity was 50 kg, while in Rac, they caught only 8 quintals. (Ćurčić 1915b, 71)

SHAFT MILLS

On the estavelle along Trebišnjica, at least 43 mills were built. These are the facilities built with hewed stone with a roof built from its bottom, while their one side is covered with sliced stone. Most of the mills was build from red soil (terra rossa) "mixed with limestone mortar, while there are also some more recent – made of cement" (Mićević 1952, 79). They are fenced with thick, high wall *(bent)* which kept the mill protected from flooding. The mill mechanism itself is placed in the neck of the shaft. After the millstone starts graining, the water starts running through the estavella to the underground increasing the power of the mill. Some mills also had the function of bastion, which was a mechanism for processing newly weaved blankets. Some of them in addition had fishing mechanism.

When built, the level of water, channel and mill were to be adjusted. Sometimes, it would come out that estavella where a mill was built did not have sufficient capacity of swallowing water, such as Vukićs' mill below Ravno, and therefore it had to be abandoned. These mills were attractive because of their specific architecture (Sandžaktar 1983, 199). High-quality building came as a result of highly skilled and competent builders who were locals, because the stone builders from Popovo are famous, especially in neighboring Dubrovnik, which is a masterpiece itself.

Most of mills are grouped between the villages Sedlari and Tulje, located on the south part of Popovo polje. There are 13 mills in this part, and in addition, in Popovo polje there are six other mills mostly scattered around the area.

The mills would be used for quite a short period of time when Trebišnjica was hydrologically active. When Trebišnjica dries out, or when polje floods, the mills would loose their function. This was the reason for the mills to be open and working day and night. When the mill was close to getting flooded, the cerials would be taken out quickly. Some of the mills would work in smaller capacities because of different hydrological changes in karst, blocking ponors, decreased flows, etc. The locals, therefore, would go into the ponors to clean the openings. Some ponors, allegedly, have channels that are accessible several hundreds meters in length. (Sandžaktar 1983, 201)

In late 70s of the 20th century, Trebišnjica was turned into a concrete channel, and only two mills remained outside the regulated flow. Only one of them still works, and others are covered with abundant vegetation, the walls and bents are ruining and ponors are covered with gravel. (Sandžaktar 1983, 201)

The mills stopped being part of the Popovo polje's day-to-day life, without any particular observation of their history. Mentioning the mills in the deeds of donation made by medieval rulers tells a lot about their age and their importance. (Petrović & Kovačina 1984, 475). The first known testimonial about them is in the deed of donation given to the Father Aleksandr of Dubrovnik by Hungarian-Croatian king - Matthias Corvinus dated November 2, 1465. People from Dubrovnik used to hold monopoly over mill building and using in the neighboring areas over certain periods. (Petrović & Kovačina 1984, 475).

Parenthetically, the mills remained in the memories of the locals as places where evil powers used to be coming, and they say that even the bravest man would not have the courage to spend a night in a mill. (Mićević

[1] *quintal - a unit of weight equal to 100 kilograms*

1952, 254). Namely, locals from Popovo polje believed that fairies and witches lived in the mills.

«Sometimes when the mill slows down or even stops completely because of the strong water flow, they believe that it was caused by an evil spirit. In Autumn 1932, I witnessed such a case in the mill between Zavala and Grmljani. More water than the shaft could hold was taken in and the mill started slowing down until it stopped completely. At that point, Milan Misita from Budim Do reached a big torch and threw it in the shaft, saying: 'There you go, you dirty devil'. In the middle mill below Ravno, there is a mill stone called '*opačac*', because it turns in the opposite direction. They say that this mill stone stops several times during the night, and when they through a large rock in it the stone starts spinning again. That is the reason that no one dares to spend a night alone there» (Mićević 1952, 254). This devilish environment is the place where the shafts of life turned into the shafts of death, where the locals from Popovo went through their most horrifying experience, not only with in terms of the shafts, but generally.

Fig. 4. Old mill covered by vegetation and the last miller Nikola Raič on it.

SHAFTS OF DEATH

During the Second World War and immediately after it, the Popovo polje shafts were used as a tool of poor political fate of this area – some of them became mass graves. Military forces were very revengeful towards the defeated ones and their community members by killing them and throwing them into these shafts, or even worse, they would throw them alive into these shafts. This is the point where several sentences should be said about the political history of Popovo polje. Since the second half of the 15th century until 1878, Bosnia and Herzegovina was a part of Turkish Empire, and subsequently, it became a part of Austro-Hungarian Monarchy. After this, the Kingdom of Serbs, Croats and Slovenians emerged 1918, whose name was soon changed into the Kingdom of Yugoslavia. Essentially, the main role in this establishment was played by the Serbian Crown, which resulted in strong political turbulences inside the country. This state fell apart at the beginning of the Second World War, and in the territory of Bosnia and Herzegovina and Croatia, supported by the fascists, a new Independent State of Croatia was established. It was divided into two zones of influence – German and Italian assuming the discriminating fascists laws. In these circumstances, the use of national issue was followed by emerging national and paramilitary forces. Apart from the regular army called «Domobrani», Croats had political army called «Ustasha», while Serbs were organized as «Cetnik» in military sense. There were also partisans, led by few local communists under a strong influence of Russian communists and Stalin. Generally, the communists were tacitly getting closer to the opposition trying to get the name of people's army for themselves, while their closely cooperated with Cetniks in the beginning in Popovo polje and south Herzegovina, and even some of them were members of both armies for a long period of time. After first bigger war crimes, Popovo polje was divided into two parts – west part mostly inhabited by Croats and controlled by Ustashas, and east part, inhabited by Serbs without any authority's control. It lasted until the end of the War, 1945. Ustashas, in the ultimate battles, decided to evacuate a part of the population that is trying to escape the battles and running several hundreds of kilometers, until they were blocked in the area of the current Slovenia. They were captured there and a number of them were severely sentenced after they came back. The shafts were very much used in the first months of the war, less during the war, and their usage was intensified at the end or even after the war. In our bibliography, we found 12 shafts in Popovo polje that were used as single or mass graves.

Jama Ržani do is a shaft whose diameter is between 4 and 5 meters and depth 35 meters; it is located along the road Trebinje – Ljubinje, and it was the first one mentioned as a mass grave in Popovo polje. Ustashas, who were fascist-oriented military forces of the Independent State of Croatia, on the 23rd and 24th of June 1941, threw 187 people – Serbs from Popovo polje. (Čučković 2003,

I., 104) Some of the sufferers saved themselves by running away from the line near the shaft. According to some sources, several days before, a Croat from the neighboring village Ravno was thrown into this shaft (Puljić et al. 2001, p.p. 443). In the following months, people from Ljubinje, Stolac, Mostar, Čapljina and other places were brought here and thrown into this shaft. According to the official Yugoslav sources, there were allegations that more than 1000 people were thrown into this shaft, which is also mentioned on the memorial located on this shaft, or even 1200 people; however, the 1990 exhumation proved that "at least 236 victims" could be identified with certainty (Dožić 1995, 364). On October 27, 1990, there was a church service above this shaft, and the bones were transported to the village Veličani, where they were buried in the memorial charnel house.

Male jame (Small shafts) are located in Popovo polje, right below the village of Cavas/Chavash/ itself. Morphologically, this is a hole whose diameter is between 3 and 5 meters and which is 4 meters deep. This shaft emerged in Autumn 1936. Due to abundant rain, the field was flooded "in a day". On the orthodox holiday – Mitrovdan, around noon, underground roaring could be heard and above Male jame, a fountain, 30 meters high emerged, and people got quite anxious and interpreted this event in different ways. In spring, after the water (localy: blato) vanished, the hole emerged on the field. (Milošević 2004, 20).

On August 11, Ustashas arrested all village inhabitants – Serbs; shot them all dead and through them in the shafts. (Čučković 2003, I 130) There were total of 101 people killed: among which there were entire families of nine, seven or less members, (Milošević 2004, 298) After the war the bones were exhumed from the shaft and buried in the memorial charnel house near the village Čavaš near Male jame. This memorial charnel house was destroyed on March 30 and 31, 1993. (Čučković 2003, I 136).

Snobitac jama on Korlati: A group consisting of 64 Croatian army "Domobrani" was brought near the shaft called Snobitac that is located on the mountain Bjelasnica, near the Drijenjansko brdo hill. This was a part of 140-domobran group who were captured by partisans in Plana near Bileća. They were "all killed with stakes and gunstocks, and then thrown in the shaft" (Čučković 2003, I 140). Allegedly, the partisans handed over these domobrans "to a group of armed people", who were in fact Cetniks, led by some Nikola Drapić. There are indications that Drapić used to be a member of KPJ and became the commander of the Cetniks battalion, but allegedly, "he was not a criminal". (Čučković, 2003 I 140)

Jamas of Hutovo: two shafts near the village Hutovo, where "total of 36 people – Serbs" were killed: Gradina, which is 250 meters away from the railway station with around "4 persons" and Hadžibegov bunar on the hill, around 1200 meters away from the railway station with 32 people (Čučković 2003, II 51). They were killed from June to September 1941. the first group was taken away in the night between June 24 and 25. sixteen people escaped from the shaft Hadžibegov bunar. (Čučković 2003, II 51)

Fig. 5. Memorial place on mass grave Jama Ržani do.

Jama Golubinka above Veličani village – at least eight Croats from Popovo polje were killed here, and seven of them were members of "Croatian Way of the Cross". This group was brought to the area of Popovo polje after the end of the war and thrown into the shaft above Veličani, and one was arrested in 1943 and thrown into this shaft. (Puljić et al. 2001, 416) The Way of the Cross or death marches in Croatian history are the lines of war military prisoners, and civilians that were following the former ones and that were found at the end of the Second World War in the area of Slovenia and Austria. They were transported by trains or by foot in different parts of Yugoslavia, where a number of them were killed after some kind of martial law proceedings, while others went through long-lasting prison sentences.

Croatian authors mention another seven shafts where executions of a smaller number of people took place, mainly individual cases: **Golubinka jama** between Zavala and Čvaljina, **Jama Ograđenica** near Kijev Dol, **Behramova jama** near Orašje, **Striježava** shaft near Čavaš village, **Jama kod Orašja, Jama kod Čavša** and **Jama kod Oraških staja.** Apart from these sites, Croats and Serbs from Herzegovina are related to several shafts in the wider region. The textbooks also mention sufferings in similar karst type, such as karrens, natural wells, karst fens, etc.

The first textbooks which dealt with shaft as mass graves published after the Second World War. The pub-

lishers were communist authorities of the time, who continued following partisans steps, and they used official archives. These official authorities offered the version according to which mostly Ustasha's quisling forces used these shafts as mass graves. Rarely, this role is given to Cetniks, such as the crime that took place on June 11, 1942, when Cetniks throw twelve distinguished soldiers after outrageous torturing into Viduška jama, not far from Popovo polje (Slavić 1986, 206). This was mainly connected to the beginning of the Second World War i.e. "genocide policy of the Independent State of Croatia". Only in the late 20th Century, after multi-party elections and political liberalization, the textbooks indicating that the shafts were used as mass graves by all local military and para-military forces. There is no proof that Italian and German forces performed such executions in Popovo polje.

In the book titled *Žrtve komunističkog terora u trebinjskom kraju (Victims of Comunist Terror in the area of Trebinje)* which is declared to be a memorial for the Serbs who were killed by the hand of their brothers (partisans), the author burdens communists with killings that took place in the villages of Trebinjska šuma. Describing the attitude of the communists, he says that they have become beasts, that they are cutting heads off mostly for nothing, that they prosecute, judge, do whatever they like, desecrate – and commit crimes, which «are not weaker by their monstrousness than the ones done by Ustashas". (Merćep *et al.* 2005, 15) The shafts mentioned here are not located in Popovo polje; they are located upstream Trebišnjica. A bit earlier, certain information about partisans' crimes in the other part of Dinaric karst – in North Croatia (Jama Jazovka) and in Slovenia emerged. Until 2005, the research done in Slovenia resulted in 410 mass graves recorded, and the information that there are another 160 mass graves that are yet to be located. (Ferenc 2005, 102). Namely, after the war, in this area, without any legitimate proceedings, more than ten thousand people were killed, and the Yugoslav/Slovenian authorities, apart from taking their lives, took away their right to be barried. According to the available data, in 134 graves, there are corps of soldiers, in 79 – civilians, in 72 – both soldiers and civilians, and there are no available data for many of them. (Ferenc 2005, 52)

Certain descriptions where sufferers of the Catholic Church parishes, which are at least partly situated on the territory of Popovo Polje are mentioned, and according to some Croatian sources, in the Second World War, there were 1537 people killed and 59 of them were allegedly thrown into the shafts. The Croatian sources blame the "Serbian" ones that they "almost entirely recorded only Serbs, and that the Croatian victims were passed over in silence". They say that the official Yugoslav sources registered only 51 out of 613 victims in these villages, and that "the majority of villages was not recorded at all" (Puljić et al. 2001, p.p. 83). These victims who were passed over in silence, especially those whose grave is unknown, hover above the landscape, which is gradually becoming a huge field of sufferings. Many of those who disappeared, allegedly, ended up in some other shafts spreading from Slovenia to Monte Negro. Some data from Slovenia partly confirm these statements. Out of all identified mass graves in Slovenia, in 108 of them, the victim are mainly Slovenians; then Croatians – in 84 shafts, while in 59 of them, there are victims of different nationalities. (Ferenc 2005, 52)

The information about the earliest known execution that took place above a shaft, which had the flavor of group revenge, is related to the beginning of the First World War. The place of suffering is Koritska jama, which is 30 km northeast of the edge of Popovo polje, close to the border with Monte Negro. The sufferers are local Muslims, presently called Bosniaks, who were "brutally killed by hajduk [highway men] and threw them in the Jama on Korita". (Hasandedić 1990, 179) The exact number of the sufferers is not know, nor are the exact circumstances of this event; it is only known that almost entire families of Dizdarević's and Redžić's were killed. Since that time, the local Muslims call this shaft Dizdaruša. (Hasandedić 1990, 179)

However, the memorial at Koritska jama, which was erected a monument in 1962, lists the names of 133 victims, mostly Serbs, that Ustashas killed in early June 1941. According to the textbooks dealing with this topic, this number is even bigger, and it is "155 victims from this area" (Čučković 2003. I, 392). It gives the statements of the Exhumation and Memorial Board members who said that in the period between 1953 and 1956, 186 skulls were counted and taken out of the shaft and transported to the memorial; however, there were no mention of any Muslims. The memorial board which was placed at Koritska jama in 1962 read: "On this place, on June 3, 1941, the invader and its servants – Ustashas, brutally killed 130 patriots of this area". On the fiftieth anniversary of these sufferings, June 5, 1991, the old memorial with red star and red ribbon was removed (Čučković 2003. I, 392), while a new one with a cross was put and it reads: "KORIĆKA JAMA / IN THIS SHAFT, ON JUNE 4/5, 1941, USTASHAS THREW 134 SERBS FROM THIS AREA. THE BONES OF THE BRUTALLY KILLED PEOPLE WERE EXHUMED FROM THE SHAFT IN 1953 AND IN 1956, THEY WERE BURRIED IN A COMMON MEMORIAL CHARNEL HOUSE IN THE CENTER OF THE VILLAGE KORITA / FAMILIES OF THE VICTIMS AND THE BILEĆA MUNICIPAL ASSEMBLY". On the memorial board below this one, there

is a ten-syllabus poem about the suffering and the obligation of never forgetting what happened. There is also the list of eight names of the survivors.

The differences between the numbers of victims that were mentioned on this memorial boards at Koritska jama and the number of skulls taken out and buried in the charnel house confirms the questionability of the accurateness and objectivity of the victims treatment and the authenticity of the research boards. As we could see, this is also applicable to the shaft called Ržani do in Popovo polje, which is one of 14 shafts in Herzegovina that was exhumed by Serbs in the period between 1990 and 1991, and whose bones were transported in the memorial charnel house in Veličani (Popovo polje) and Prebilovci (Neretva basin). In one report, there is a reminder that this exhumation was not performed upon the order of investigating judge, because this request was left without any response. (Dožić 1995, 364). The reveled number of victims is five times smaller than the list on the memorial board. The exhumations were carried out at the down of a new war and they were used a sort of propaganda to stir it up. Many articles were published, such as the one published in the Belgrade's magazine *Ilustrovana politika* (1668, 23. X 1990) telling a story about the shafts, which was dated in 1941, when a Bosniak from some neighboring village, who was a member of Ustashas "one morning, came with a bracelet made of eye balls on a piece of wire". How disturbing and distracting these reports were for the families of sufferers tell the following sentence which could be found in many reports: (in the shaft) «The bones of a dog were also found there. No one knows if the dog was thrown down alive to worsen the horrible sufferings of the people by his bites or if this was just another sign of humiliation of Serbs" (Čučković 2003. I, 112). The speleologists know that animal bones are often found in Dinaric shafts, whether it is a corpse that was thrown down or an accidental falling into it. Moreover, there are many anecdotes and legends about a dog that fell into one shaft and emerged in some other downstream spring.

Exhumations are more or less protected with a dose of respect; however, sometimes they are being carried out in a series of prosaic actions, or even worse than that. Namely, over time, the bones of different military forces members and civilians, or even bones of the cattle from the neighboring villages are accumulated in a shaft. On one occasion, a certain amount of bones was taken from the top of the pile that was found in the shaft and which also included animal bones – all of them were put in the memorial charnel house. On some other occasion, also in the middle part of Dinaric area, speleologists were assigned to pull out a part of skulls (the organizer was happy with this symbolic part of a skeleton) out of many that were laying down. As they could not find "those who were ours", with a bullet hole, their next assignment was to make a hole in each accessible skull with a nail. (Božičević 1991, 53) Anything will do!

We will not explore further ethnological and sociological reasons of these sufferings, because it requires serious analysis and much more available space and time. We would only advise that it would be wrong and harmful to conclude that the locals solve their mutual problems and conflict through mutual executions. On the contrary, no author remembers that a peasant killed another peasant, save the wartimes. At the same time, social solidarity and respect are traditional values that are generally recognized in this area. The shaft-related crimes have certainly bigger time and space coordinates. It is enough to give only two recent examples: in late 20th century, the Special Forces of Serbia kidnapped the former Serbian Presidency member, I.S., and killed him and threw him in a limestone shaft in Fruška gora mountain. The other example: Portuguese public was horrified with the news released in February 2006, according to which a group of juveniles tortured a sick prostitute, and threw her in ten-meter deep shaft in Porto where she died. Also, literature works of Turkish Nobel-prize winner Orhan Pamuk, put this social experience into a context.

BEYOND FRAMES

What is commonly called jamas by the locals from Popovo polje was the subject of extensive scientific research, particularly during the late 20th century. The results gave some element for the picture which makes Popovo polje a distinguishable karstological phenomenon globally. Numerous and different researches were conducted and unusually huge amounts of money were spent, when a number of methods was applied, some of them being completely new. In geo-morphological sense, many karst phenomena, well-developed ones, were described. In hydro-geological and hydrological sense, there were many underground links and underground water flows, bifurcations and co-streams. Biologically, ponors in Popovo polje are the prime numerous sources of underground fauna. Accordingly in Crnulja, *Marifugia cavatica* was found – the first fresh water serpulid worm in the world. Special attention was caught by the discovery of *Congeria kusceri,* the only known underground shell in the world

(Sket 2003). This discovery was even more spectacular, because scientists mostly believed that this shell was a fossil organism. Only in Vjetrenica, which makes an integral part of the karst system in Popovo polje, there were at least 37 underground species found and discovered for the first time. In Popovo polje, so far, there is more than 20 underground species living only in this area, and this polje is considered one of the most abundant places of subterranean fauna in the world. (Sket 1983). Vjetrenica is a cave that has been attracting attention of many researches and adventurers, as well as common men throughout history because of the phenomenon related to the strong wind at its entrance. It lays foundations of research history on the east Adriatic coast. It was adapted for tourism before the Second World War, and after the War, a path almost 1000 m long with lightning was built. Non-biological research of shaft were stirred up after the construction of the hydro-power system on Trebišnjica, which resulted in complete isolation of ponors and estavellas from the hydrological and environmental cycles, and this was also followed by a similar perception of the events related to the shafts in the area of Popovo polje. The underground of Popovo polje has been deprived of four billions cubic meters of water per year (Milanović 1983), which led to destruction of the underground habitas. Although the consequences have not be explored, it was registered that abundant colonies of *Marifugia cavatica* were destroyed in their primary deposit, where this organism developed tens of meters long biogenic travertine stones. However, neither the emerging not the disappearing of Marifugia and ecologically similar species had not been registered in the perception of the Popovo polje locals.

Fig. 6. Gape of ponor Crnulja in Popovo polje, locus typicus of tube-worm Marifugia cavatica.

CONCLUSION

According to the presented literature, mass graves are most likely the most impressive experience of the "jamas" in Popovo polje in the 20th century. The shafts as friends of life – in their capacity of fish shafts, mills or fresh water oasis – have not been mentioned a lot. One of the most dedicated authors, the collector of ethnological substance about Popovo polje, Ljubo Mićević, was himself a victim of massacre at the Jama Ržani do, and his book was published after his death. Most detailed descriptions of fish shafts and their links with the locals were made by Vejsil Ćurčić in his paper dated in 1915, and nobody followed him at all. Public awareness has not still been raised enough to understand karstological or biospeleological image of the shafts. If this was not of practical use for the people who led their life in these areas in pre-industrial and industrial age, nowadays, at the time of advocating sustainable development, this represents not only the obligation to preserve the environment, but also, it could be a big economic advantage. Generating negative views about environment, regardless of auto-destructive consequences, have connotations of social choice, and could be turned into better solution. The shafts of life are still being neglected, while the shafts of death are assigned an important role. This requires additional research which will enable a comprehensive analysis and re-evaluation of the karst landscape of Popovo polje and Dinaric karst at all.

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NON-SPECIALISTS PERCEPTION ABOUT ENDOKARST AND EXOKARST SCENARIOS: VISIONS FROM HIGH SCHOOL STUDENTS

LAIČNO DOJEMANJE KRAŠKEGA PODZEMLJA IN POVRŠJA: PRIMER VISOKOŠOLSKIH ŠTUDENTOV

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Abstract UDC 159.937.52:551.44

Luiz Eduardo Panisset Travassos & Edson Gomes Travassos & Lucília Panisset Travassos & Luiz Carlos Panisset Travassos: Non-specialists perception about endokarst and exokarst scenarios: visions from high school students

The aim of this work is to recover some methodological aspects of the study about the mind representations of caves in Brazil. The basis of this research consisted of one essay, approaching the social representations of a particular group of high school students on the exokarst and the endokarst. The results showed that the meanings vary only slightly, however, the most interesting result was due to the fact that students, who had already visited caves in some period of their lives, still held "negative" concepts regarding this environment even before visual stimulations. About 640 words associated with the exokarst and the endokarst were mentioned, emphasizing: fear, dark, shadowy, skull, hidden places, fantastic and beauty, which helped identifying relations between the cultural and psychological aspects of the group, mainly general views about the obscure and mysterious aspects of this landscape and its prominence over natural beauties. Analyzed data showed that the development of new research on mind representations of caves is very important, mainly for environmental education programs promoting adequate concepts about caves and extending activities of educational ecotourism in Brazilian caves.

Key words: mind representations, environmental perception, symbols, caves.

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Luiz Eduardo Panisset Travassos & Edson Gomes Travassos & Lucília Panisset Travassos & Luiz Carlos Panisset Travassos: Laično dojemanje kraškega podzemlja in površja:
primer visokošolskih študentov

Cilj tega dela je potrditi nekatere metodološke vidike preučevanja duhovne predstave o jamah v Braziliji. Osnova te raziskave je poizkus, približanje družbene predstave določene skupine visokošolskih študentov o površinskem in podzemeljskem krasu. Izsledki kažejo le majhne medsebojne razlike. Vsekakor pa je najpomembnejši izsledek, da študentje, ki so že kdaj v svojem življenju obiskali kako jamo, imajo do podzemeljskega okolja »negativen« odnos, še pred vizualno stimulacijo. Naštetih je bilo okoli 640 besed povezanih s kraškim podzemljem in površjem, vključno: strah, tema, sence, lobanja, skrivališče, fantastičen in čudovit, kar pomaga določiti razmerje med kulturnimi in psihološkimi pogledi skupine, namreč splošni pogled na obskurni in skrivnostni vidik te pokrajine ter prevladovanje tega nad naravno lepoto. Obdelani podatki kažejo, da je zelo potrebno razvijanje novih raziskovalnih metod v zvezi z duhovnimi predstavami jam, to je okoljskih vzgojnih programov z ustreznimi koncepti o jamah in da je potrebno razširiti izobraževanje v ekoturizmu tudi na brazilske jame.

Ključne besede: duhovna predstava, zaznavanje okolja, simboli, kraško površje, jama, Brazilija.

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INTRODUCTION

As it is known, human relations with caves take us back to times of cults and myths of highly symbolical meaning, depicted by cave paintings or in the representations of caves as birthplaces of gods, heroes and nymphs.

In some other cases, karst regions and caves appear as places where conflicts between the good and the evil took place, as sacred or profane sites, and sites where topophilic or topophobic feelings could be expressed especially by folk tales and traditions. Therefore, mind representations determine, in its essence, the development of human beings and its social existence.

When studying collective mind representations (the imaginary), we are compelled to understand that "mental imaging systems and its defining structure as to facilitate understanding of the dynamics of images are incorporated as collective content, resulting in visualization, social representation and preconception that could compromise the quality of a view about a particular environmental scenery."(Figueiredo 1999, 165)

For many authors, however, studies about collective mind representations could be considered as an instrument of knowledge and comprehension of a particular social group. "Each culture, each community and, even each level of a complex community has its imaginary, which manifests itself from human experience, from the most social collective through to the most intimately personal " (Mendes 2003, 72) by which society expresses its temperament, its character, its doubts and desires when trying to establish a broader sense of perspective to human existence. Such a fact can make people share the same way of thinking (Mendes 2003).

Fig. 1: General view of the Cerca Grande massif, Matozinhos (MG) (ph. H.C. Kohler).

We can use a regional Brazilian Legend (Lenda do Lapão Velho) as an example to illustrate a social group temperament expression, written by Mendes (2003), showing discrimination and religious intolerance with the practice of candomblé, an African type of religion/ritual. The Legend states that, after a ritual, the cave closed giving way to the opening of another cave, where Catholic masses take place nowadays.

When mentioning Figueiredo, Meneses warns us that concepts of image, imaginary and imagination have the fact they all refer to the spectrum of sense and meaning in common. They involve the phenomena of production, storage, circulation, consumption, recycling and discharge of operations as well as meanings that are fundamental to the formulation and establishment of hierarchy of values generated by any given community, essential to its organization (Meneses apud Figueiredo 1999, 165).

And this is how the concept and pre-conceived images about caves appear. History shows that the human being has always been connected to karst areas, either for ritual activities or contemplative ones. As it is already known, pre- Colombian civilizations used caves as drinking water fountains, for religious rituals, burial ground and refuge, for instance.

The magnificence of the exokarst and the beauty of the endokarst are the sources for the development of collective mind representations (imaginary), "important element for the rising of legends and fables associated with more common myths" (Teixeira et al. 2003, 11), where the myth function is the fixing point to exemplary models of several rituals and expressive human activity such as feeding, sexuality, work, education, moral, etc. (Elaide apud Teixiera 2003).

It is believed that the most common studies about the human relation with caves are those related to myths and not to legends, since myths have figures that are common to cultures and varied places. This is the case with the apparition of Our Lady of Lourdes (France), the images of Our Lady of Lapa, in Portugal (15th century), in Antonio Pereira, Minas Gerais (Brazil, 18th century), or in Vazante, Minas Gerais (also in the 18th century). In these places percolation of water in the cave (Lapa) walls is related to the apparition of the Saint, giving miracle properties to the water.

As to caves, some people do fear them for believing that they are homes of strange beings and its rooms can sometimes take them to places with no way out. Such places can also be a ground to be respected for its natural

beauty, the healing power of its waterways and its divine origin (Mendes, 2003).

Silva (2003) says that, for a "rational" contemporary society, a myth is always born from a fantasy explanation of reality, inferior to scientific knowledge, and sometimes the history behind myths hide records of some political and religious aspects of a region.

To understand the relation between the individual and the space under consideration, ideas and exposed concepts is the same as understanding the human experience with the environment in all its complexity. Yet, people can understand feelings, perceptions, attitudes and underlying behaviors under a holistic conception of relations between individual or collective spaces, either known or unknown, which in counterpart can become places or not (Silva 2002).

Plato, the Greek philosopher, used a cave imaging as a metaphor to reveal the duality between the sensible and the tangible world, influencing thought through the "Cave Allegory". Everything that "the prisoner", the main character, knew as reality was only a reflex, artificially created inside the cave, without much similarity to what existed in the real world.

Comelim (1993) says that in the Classic Ancient Greek and Roman mythology hell was considered as an underground place to where souls would be sent after death. Such places were located deep under Greece and Italy, extending through to the extremes of the world. Therefore caves, cracks or openings on the ground would be gates to hell that no one would dare to explore.

According to Aranha and Martins (1992), the illuminists disregarded imaging/imagination when saying that the imaginary and the concrete reality are contradictory, sources of illusion, fantasies, the lack or denial of reason. Therefore, such collective representations did not contribute to the development of science.

For Mariano Neto (2003), by the 18th and 19th centuries there were only fragments left from Plato, as a foundation for critics about the domain of reason as the only source to access truth. Such fragments displayed some forms of resistance to the dogmatic rationalism shown by Kant in his work "Critique of Pure Reason"(1781).

"Criticism in the nineteenth century was aimed at the excess of Cartesian Mechanicism. Maybe that is where we can find the first steps towards rescuing image not only as the object of knowledge but as a whole object capable of representations." (Sartre 1980, 327).

With the arrival of the 20th century, man is not only living the moment of the practice and exercise of modern science principles but also a moment of intense polemics in relation to the real, the reason and the imaginary (Mariano Neto, 2003).

Nevertheless, shifting away from these paradigms is extremely difficult according to Mendes (2003, 72), who believes that "domain of imaginary is a group of representations that lays beyond the limits of confirmation. Each culture, therefore, each society and even each level of society has its own imaginary, which appears as a result of all its human experience, from the most social collective through to the most intimate personal one".

A recent movie, "The Cave" (2005), depicts a group of scientists facing the dilemma of discovering the ruins of a 13th century Church in Romania, that was obstructing the entrance to a huge underground cave, home to demon creatures, confirming the negative feeling a lot of people nurture about this type of environment. It is worth mentioning that, as it has been already said, the Church exists as a symbol of protection against the so called "gateway to hell" of ancient times. Another movie, "The Descent" (2005), has its plot based on a frustrated speleological expedition and the characters found themselves corned and threatened by horrendous creatures.

"The Chronicles of Narnia" establishes an analogy to caves when it is mentioned that the shadows of a wardrobe could take people to a magical world. A world dominated by a witch that lives in an ice cave/castle. At the end, the fight between the good and the evil takes place at a beautiful poljé, a place of majestic beauty emphasizing the general idea of fascination for the exokarst.

In the book "Landscapes of Fear", Tuan (2005) mentions the work done by Berr (1930) about a great Alpean explorer, Johann Jacob Scheuchzer. This particular explorer dedicated all his life to the study of plants, minerals and ice movements of the European Alps, from 1702 to 1711, creating a catalogue of Swiss dragons.

According to the author, "the best dragons lived in Grisons, the biggest and the least densely inhabited place of remote Swiss. This region is so rugged with so many caves that it would be strange not to find dragons there." (Berr apud Tuan 2005, 129).

Interest in this kind of subject is due to the disseminated views related to the exokarst, which are normally linked to positive feelings, to religion and to the glorification of natural beauty and leisure, whereas those linked to the endokarst sometimes display negative feelings, such as dark and muggy places, as well as housing for unthinkable creatures.

People fear caves because they believe in supernatural occurrences, places where "animals are hidden or places where beings from other worlds live (…), in other places however we are going to find caves that are respected, with a mystical aura around it or a scenery of religious manifestations" (Mendes, 2003, 77-78).

According to Marin, Oliveira and Comar (2005), we cannot understand the relationship between man and

the environment without taking in consideration those non-rational human dimensions. In this specific case, the imaginary clearly defines the social existence and the relation with space/place, so that when we talk about environmental perception we consider the several possibilities of associated symbol construction.

To some, in the words of Barbosa, Nogueira and Neves (1999 71), "the so called cave mouth is a lot more than a simple entrance, its is a portal, a passage to a new universe where rats change into bats, a place where God imprisoned Satan (...)" or even the confirmation of a divine creation that must be adored and preserved, where water turns into rock.

On considering Humanistic Geography, we can notice the recent display of the environmental perception tendency in a lot of sciences, underlying phenomenology and existentialism, valuing man personal experiences with its environment for the implementation of more efficient strategies in the practice of environmental education. According to Ribeiro (2004), because this is a pedagogical process, it requires time and monitoring, aim adjustments and constant attention.

Therefore, it is believed that investing in environment perception is of fundamental importance in order to improve our knowledge and be able to best explain certain attitudes and values of a given social group in relation to its environment. "Human studies are aimed at the relations established by individuals, feelings, perceptions and attitudes of human being about space and place as far as live experience" (Silva 2002, 73)

Humanist researchers are turning themselves to the comprehension of experiences, perceptions and habits of social groups or individuals with places and non-places, seeking to find it in phenomenology, "the most important philosophical basis of Humanistic Geography that consider all knowledge as derived from the world of human experience, where ideas and other things are indissolubly linked into each other, making up only one phenomenon." (Silva 2002, 78)

In his work about topophilia, Tuan (1980, 26) says, "a symbol is a part with the power to suggest a whole (...). In such a rich world in terms of symbols, objects and events take on meaning which can seem to be arbitrary to estrangers". Some forms of interaction with spaces turn them into places, in a process of adding values that sometimes are not understood by those people alien to certain social groups.

Patlagean (1990) considers the collective imaginary as a group of mental representations that extrapolate boundaries of confirmation by experiences and by authorized deductive connections. From that point on this research seek analysis of man capacity of giving meaning to symbols, showing its importance for comprehension of collective values; further enhancing work related to human representations of caves.

MATERIAL AND METHODS

Because it's believed that studies of karst can dwell perfectly in the field of physical and human research, the work was carried out from bibliographic analysis of the relations between mind representations, the imaginary and caves. Furthermore, this discussion was enhanced by knoweledge exchange with a close friend, Professor Luiz Afonso Vaz de Figueiredo and other colleagues interested in the subject.

The methodology was adopted and adapted from Figueiredo (1999) and the main methodological focus was the creation of an exploratory essay, in February 2006, with the aim of establishing a diagnosis about the view of a certain group of students about karst landscapes. The authors felt the need to treat the subject with the group after a brief explanation about the karst ecosystem, which sometimes attracted negative questioning.

Thus, the study about social representations of the cave concept was developed and divided in two parts, involving 67 high school students from two different 11th grade classes of a private school in the city of Belo Horizonte, State of Minas Gerais, Brazil.

Fig. 2: Hum of Vargem da Pedra, Matozinhos (MG) (ph. L. Travassos).

In those two groups, collective interviews were conducted, starting from a direct stimulus related to their

pre-concept of caves. They were asked to record 5 (five) key words about the word cave, writing the first ideas that would come to their minds when the word cavernas (caves) was mentioned. After recording those key words, they would answer whether they had already visited any cave before and if they had any intention of doing so in the future.

In the next activity the interview was started from another direct stimulus related to the theme, when after viewing 5 (five) slides, each student should record one single key word for each image and answer the same question about visiting a cave. Slides included images of the exokarst and the endokarst, such as cave entrances, dolines and speleothems.

RESULTS AND DISCUSSION

Regarding the characterization of the public interviewed the following data was gathered: it occurred the predominance of female interviewees (53.7%), against 46.3% males. Out of these, 67% had already visited a cave against 33% students that have never visited a cave before.

Results showed that the values given to caves did not vary much between the two groups, for they were relatively equal in terms of age, between 17 and 18 years old, and at the same social level. However, some variations were noticed when the stimulus was treated through slides that demanded even more personal perceptions.

Inside the two groups, two sets of 335 words were registered associated with the noun cave (with some recurrence) and the other 335 related to the keywords after a visual stimulus.

Records were restricted in its majority to the words that expressed negative feelings such as fear, darkness, shadowy, muggy, skull, hidden places, dragons, loneliness, lack of breath, mystery, danger, animals, amongst others, even in the universe of students that had already visited a cave before.

Besides, a curious phrase was recorded: "a place to whisper". When confronted about the motive of someone having to whisper in such an environment, the answer also had a negative meaning, being justified because "if we are to talk loudly a stalactite could fall and kill people."

After being asked about the reason for someone to express topophobic feelings in relation to caves, even after having already experienced that environment, some of the students said they had not visited a cave in the company of someone that knew what he was doing or saying. Such a scenario shows the importance and need of truly qualified guides in any tourist activity, mainly in the tourism related to caves.

Even with all the symbolism related to "caves", we can still identify words from scientific background such as stalactite, prehistory, rock, water, natural beauty, biodiversity, intemperism, acidulation, amongst others, depicting previous contact with the theme.

After the visual stimulus about the exokarst and the endokarst, words such as fantastic, wonderful, awesome, knowledge, tranquility, force, adventure and perfection could be identified, and around 98% of the interviewed students who had never visited a cave before showed desire to do so in the near future.

According to Figueiredo (1999), the question of collective imaginary about caves is present in the verbal tradition of the population that lives in its vicinity. Such representations are also shared by those living in urban areas who have already had a chance to visit a cave or have the desire to do so.

People from the cities normally receive a massive quantity of information about speleological activities through the media or store misguided representations throughout their lives leading mainly to wrong views about this type of environment. Fear of bats or other animals are common occurrences. Lack of air is automatically evoked when we talk about the underground.

A closer look at the data confirmed the need of a series of studies emphasizing the importance of developing effective programs of Environmental Education in order to facilitate learner access to better quality of information about the karst environment. In 1781, Immanuel Kant said that only reason can be limited by the senses contribution and this is why we cannot produce a complete set of knowledge about reality. Therefore, the reality perceived by students is extremely influenced by the senses, mainly at the age of the group surveyed.

For Tuan (1980) the meaning of perception, attitude and values overlay themselves, clarifying the context expressed in each of these processes. Such processes consider that adopted attitude to the world is formed by a long path of successive perceptions and experiences. Attitudes adopted by people in relation to their environment reflect their interests and values and their personal view of the world. It is therefore a conceptualized experience, partly personal, and in its majority, social.

With this study we verified the need of further elaboration in such a theme for this particular group of people, and the importance of a more technical and structured visit showing the reason behind environment preservation, mainly of the Karst. Guide training and teacher

awareness can contribute enormously for a change of feelings in relation to the underground world.

Therefore, studies about perception and the imaginary must be seen as a phase in human relation with the environment, and it is important to involve community in the solution of possible problems.

We are aware that field work represents an extension of "conventional" school syllabus for subjects of the so called Earth Sciences, indispensable for the consolidation of theories and concepts that somewhat contribute to the development of specific abilities in some areas of knowledge.

Practical exercises of geographical landscaping watch, development of sensory abilities for environment perception and comprehension of basic notions of positions for orientation are essential in the formation of conscious citizens capable of exercising full citizenship.

The line of reasoning used in this work agrees with Serpa (2001) when he says that the environment perception, personal experience and cultural characteristics of the inhabitants in each place play an important role in the relation between man and the environment, and must be used as a starting point for a better urban, regional, landscaping and environmental planning. Then the chances of local people's needs being met become higher and better.

"Environment perception is, in this sense, a vehicle that identifies memory rescue, being able to reveal and even justify behavioral patterns in relation to human being and its environment". (Marin, Oliveira & Comar 2004, 104). As it has been said before, if caves are feared or adored by certain groups, we must seek to decode which are messages being transmitted.

Fig. 3: The first cave arranged for tourist visit in Brazil, Napa Nova do Maquiné, Cordisburgo (MG) (ph. L. Travassos).

It is known that karst landscapes have a dynamic physical-chemical peculiarity and because of this, they are more sensitive to the exploitation of its resources. Many qualitative and quantitative studies deal with the processes related to the physical, biotic and economical environment but we can't disregard any work that approach this landscape under a more holistic view, not forgetting cultural and human variables.

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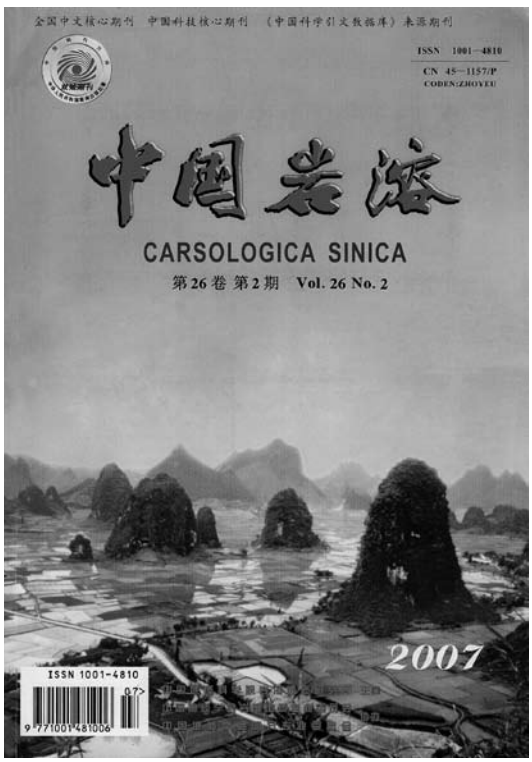
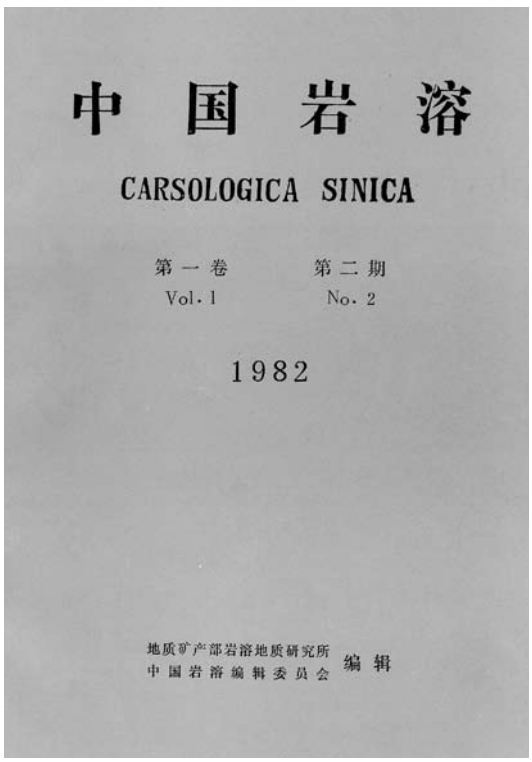
REVIEWS AND REPORTS

POROČILA

25 YEARS OF CARSOLOGICA SINICA





In 1982 Chinese karstologists from the Institute of Karst Geology at Guilin started the quarterly journal CARSOLOGICA SINICA (ZHONGGUO YANRONG). The journal is under the aegis of Chinese Academy of Geological Sciences, patronized by the Commission of Karst Geology and by the Committee of Speleology in the frame of Geological Society of China. And not only sponsored but also edited and published by the well known Institute of Karst Geology at Guilin in the heart of world famous tower karst along the river Li. Chinese karstologists not only started but they succeeded to edit the journal through the quarter of a century without interruption. In this year number 1 and 2 of the volume 26 have been published already.

The major topics of Carsologica Sinica include basic theories, hydrogeology and engineering, environmental and ecological geology, geography, forestry, agriculture, tourism, and the environment protection. Of course, all the topics are related to karst. According to the topics is the circle of the readers and users of the journal. Carsologica Sinica is high ranked among the periodical publications of China and it is included in different foreign (Georef, Pascal, International Union of Speleology, Current Titles of BCRA and others) and in leading Chinese databases. Of the last mentioned Carsologica Sinica has high input factor (0.54 – 0.84) and it is ranked between 181 – 399 of 1608 Chinese publications. By an interesting and quite unknown indicator, the rate of error lower than 2 o/oo, the journal is ranked very high too. The high appreciation of the journal must not surprise regarding the immense and so various Chinese karst and the fact that Carsologica Sinica is the only public academic publication in the field of karstology in China.

In 25 volumes of Carsologica Sinica there are more than 1 200 papers. The emphasis is on the fundamental karst research, on development of karst resources and on applied research of karst resources exploitation and protection. If we compare the source of information for the

articles there is quite a big difference between Carsologica Sinica and western journals of the same type: here the source are mainly (80 %) National Natural Science Foundation Projects and National Scientific and Technological Key Projects. It is difficult to estimate journal's great contribution to the science of karst. For sure among the authors there are eminent and the most known Chinese karstologists, that means known worldwide. In the first volume (1982) already appeared the names of Yang Mingde and Zhu Dehau, the colleagues which the members of Karst Research Institute from Postojna met often in China or in Slovenia. At that time the article on limestone caves in Guilin area was published by Prof. Zhu Xuewen. Looking the contents of the last number (volume 26) there is the article on Wulong karst system by the same author. Among younger authors known to Western karstologists I have a pleasure to mention Chen Weihai. For Western sphere maybe it is easier to imagine importance of the authors by citing Marjorie M. Sweeting and Peter Bull (Great Britain), Claude Drogue (France) and Paul Williams (New Zealand) as few examples.

In 25 years also the image and technical possibilities developed. First numbers measured 18 x 26 cm, while the recent ones are of bigger dimensions (21 x 30 cm). At the beginning the cover was simple in one colour while volume 26 (2007) has a nice full page colour photo of "fenglin" karst. Likewise can be said for the inner pages where there are colour illustrations now. It is worthy from the point of non-Chinese speaking readers that from the first numbers already most of the papers have an English abstract or summary. In the volume 26 there are also key words, texts to the illustrations, and some additional explanations in English. It is self-understanding that the papers of foreign authors are in English. But recently there are also papers of Chinese authors, published in English in Carsologica Sinica, for example "Geophysical Prospecting of Karst Water in Yunnan Province" by Wang Yu, Yuan Dao-xian and Yang Shi-yu. But there are exceptions regarding foreign authors too: in 2006 a Supplement to volume 25 was published with 11 papers of foreign authors talking about "tiankengs" – in Chinese.

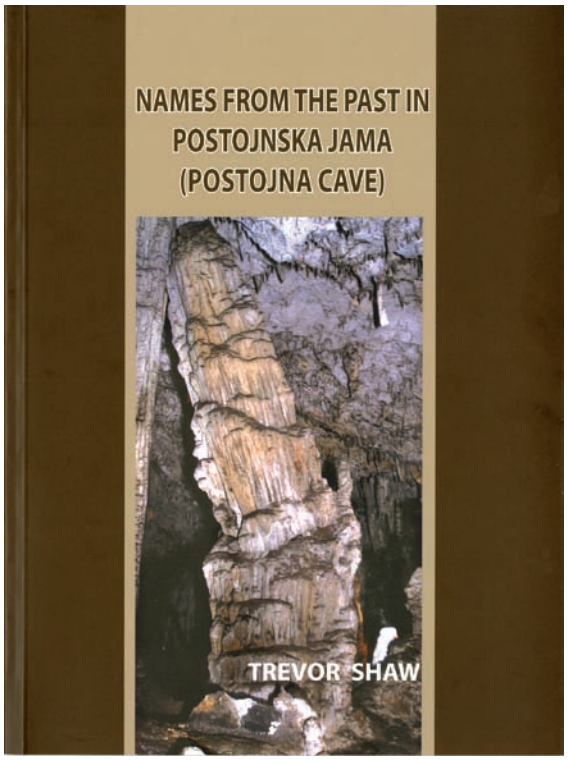
The last but not least the editors have to be mentioned too. 18 years the post and heavy duty of Editor-in-Chief was held by Yuan Dao-xian succeeded by Liu Zai-hua, also very important figure in Chinese karstology. They were helped for a long time by Assistant Chief-Editor Wei Fucai. To help to and to support the editorial policy foreign karstologists are included into the editorial board, A. N. Palmer, J. M. James, T. Waltham, W. Dreybrodt and the author of this report.

By my opinion the "Western" karstologists are using the information and data mainly upon karst in China accumulated in 25 volumes of Carsologica Sinica far too little. The language barrier is very important but it must not be decisive. English abstracts, summaries, key words, together with illustrations can be important source of Chinese examples of karst as well as a window to the thoughts and notion of karst by Chinese researchers. In spite of bibliographical bases Carsologica Sinica is included it is much less used and appreciated as it should be. It is seen by the citations as well as the use by researchers in libraries. To be honest, the journal is not so wide spread in Europe and so it is not easy to get wanted number or article. I guess that there is no complete issue of 25 volumes in the whole Slovenia, Karst research Institute library included.

What kind of good wish to express for this 25th anniversary? To keep on the work, to keep on the quality of the contents and of the layout of the journal and disseminate it as largely as possible.

Andrej Kranjc

TREVOR SHAW: NAMES FROM THE PAST IN POTOJNSKA JAMA (POSTOJNA, CAVE). ZALOŽBA ZRC/ZRC PUBLISHING, LJUBLJANA 2006, 151 PAGES



Postojna cave is the show cave universally known from some centuries. For this reason the cave has been quoted in a number of manuscripts, reports and publications. No wonder, therefore, if in the course of time the cave was known with different names. Its location, close to political borders, resulted in another reason of changes since the territory belonged respectively to Austria, Italy and Slovenia. Once again Trevor Shaw produced another book in the framework of the history of speleology. If I am allowed to make a comparison he, as an expert "truffle dog", explored archive, libraries, files and retrieved a number of detailed pieces of information on the name of the cave itself and its main features during the last centuries.

This book is a precious contribution to the knowledge of the history of the Postojna Cave and should find a place in the library of any person interested to this argument for 16 €.

Arrigo A. Cigna

E. BURRI (ED.) – THEMATIC ATLAS OF FUCINO. HYDROGEOLOGICAL MAP OF FUCINO (SHEET 1); GEOMORPHOLOGICAL MAP OF FUCINO (SHEET 2), AGENZIA REGIONALE PER I SERVIZI DI SVILUPPO AGRICOLO – ABRUZZO, 2005

The Fucino Basin is one of the larger in Italy. In prehistoric time, between the bronze age and the Roman republic the local population firstly attracted by the lake itself had to face some floods since the basin had no drain. During heavy rain the lake surface increased too much with problems for the local inhabitants. They tried to discharge the water into a sink hole without a real success. During the 1st Century a.D. the Romans excavated a tunnel to discharge the surplus water. Unfortunately after some centuries the material transported by the water and possibly also a seismic events chocked the tunnel. In the XIX Century a rich person, Prince Alessandro Torlonia, decided the excavation of a new tunnel, partly replacing the Roman one, and the lake was transformed into a very fruitful soil. Obviously also the fishermen had to transform into peasants!

The publications reported above give a full detail of the characteristics of the area with the contribution of many scientists belonging to different organisations dealing with many aspects. Each sheet consists in a map and a booklet in Italian. The maps have also titles and legenda in English.

The Hydrogeological Map of Fucino, 1:50,000, (Sheet 1) gives a very detailed view of the different aspects of the behaviour of water in the basin. In fact in addition to the hydrogeology, also others issues were considered as the pollution due to phosphates, nitrates, ammonia and the vulnerability of the aquifer including also the distribution of well in the area.

In addition to the map, a booklet of 74 pages includes a full description of waters in the Fucino Basin both at the surface and underground. The use of water for agriculture and the evolution of agriculture after the 2nd World War are described.

The Geomorphological Map of Fucino, 1:50,000, (Sheet 2) in addition to a geomorphological description strictu sensu , includes also a number of historical pieces of information which are very interesting on account of the evolution of the area since a prehistorical time. As before, a booklet of 66 pages supplies data on many aspects as pleistocenic and holocenic deposits, geological details and karst phenomena in the area concerned

This Thematic Atlas will include in the future other maps in addition to those here described and is a very useful tool for anyone interested in the evolution of a karst area where the human action played a relevant role.

Arrigo A. Cigna

E. BURRI (ED.) – BREVE STORIA DI UNA BONFICA COMPLESSA. AGENZIA REGIONALE PER I SERVIZI DI SVILUPPO AGRICOLO – ABRUZZO, ÉDICOLA EDTRICE, CHIETI, 2006: 1-27.

If the publications described before have a scientific interest, this one is fundamental to have full information on the Fucino Basin from antiquity to the present time. A short history of the development of the Fucino Basin is reported in a nice in folio booklet, which includes also a number of interesting drawings taken from old publications in addition to the text. Many of the figures are reproductions of posters which can be seen in the Park of Incile. This is a protected area including the artificial outlet of the basin.

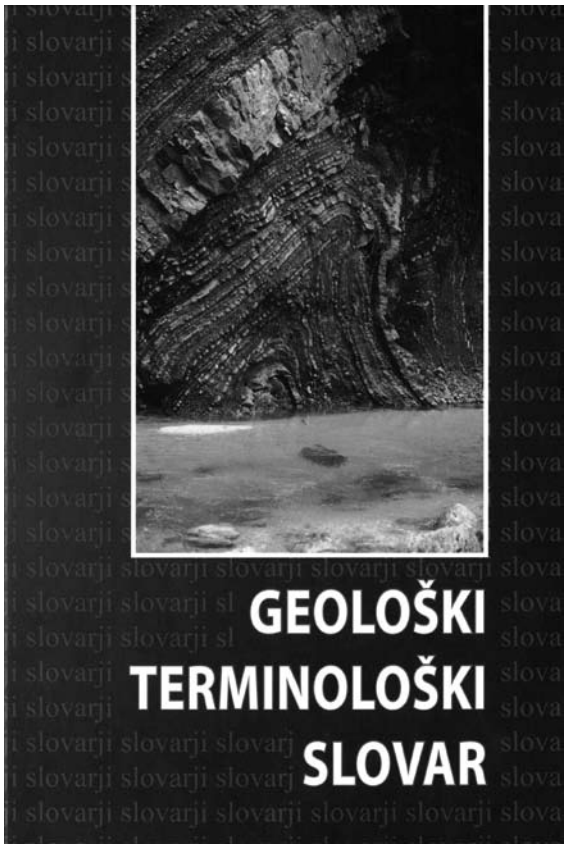
This booklet is a precious guide useful both to local visitors and to person who have not the chance to visit the area. As it is evident the history of the Fucino Basin, i.e. of a lake that is no longer a lake, is extremely interesting because it spans from prehistory to present and it is a record of a number of actions aiming to control the water level and avoid troubles to the farmers.

The most successful intervention by Prince Alessandro Torlonia (who said: "Either I succeed to dry the lake or the lake dries me!") transformed totally the basin and the whole lake area was changed into a rich agricultural plane. The Prince recovered the large amount of money by renting the land to farmers at conditions that modern trade unions would not agree with.

The persons living in this new land had a rather little freedom because they were not allowed to move around outside their own field and had to pay the water of the wells, because the water was still owned by the Prince. Only after the 2nd Wold War more modern criteria were applied. Today the area is divided into about 9000 farms with an average surface of 1.5 ha.

Arrigo A. Cigna

GEOLOŠKI TERMINOLOŠKI SLOVAR
Založba zrc, 2006, 331 str.



Izšel je Geološki terminološki slovar avtorjev akademika, prof. dr. Maria Pleničarja, prof. dr. Jožeta Duhovnika, Dragice Strmole, prof. dr. Jerneja Pavšiča, prof. dr. Vide Pohar, dr. Polone Kralj, prof. dr. Dušana Kuščerja, prof. dr. Rajka Pavlovca in prof. dr. Danila Ravnika. Izdajatelja sta Oddelek za geologijo Naravoslovnotehniške fakultete Univerze v Ljubljani in Inštitut za slovenski jezik Frana Ramovša ZRC SAZU, založila pa ga je Založba ZRC SAZU. Slovar je uredil Jernej Pavšič, za leksikografsko in jezikovno redakcijo je poskrbela Zvonka Leder.

Geološki terminološki slovar je nastajal pet desetletij in je delo več generacij strokovnjakov s področja geologije.V slovarju so zajeti geološki strokovni izrazi, ki pokrivajo praktično vsa področja geološke vede in so izpisani iz slovenske strokovne literature. Slovar zajema tudi novejše strokovno izrazje, ki izvira predvsem iz angleške literature in poleg že uveljavljenih predlaga tudi nekatere nove strokovne izraze, ki jih prinaša razvoj stroke.

To je prvi slovar geološke terminologije v slovenskem jeziku in obsega 10.811 enobesednih ali večbesednih geoloških strokovnih izrazov. V večji ali manjši meri zajema vsa glavna področja geološke vede: mineralogijo, kristalografijo, petrologijo, sedimentologijo, paleontologijo, paleoekologijo, stratigrafijo, geologijo kvartarja, fizikalno geologijo, geofiziko, seizmologijo, inženirsko geologijo, hidrogeologijo, geokemijo, nahajališča mineralnih surovin in regionalno geologijo. Vsebina je razdeljena na poglavja Uvod, Viri, Pregled piscev gesel po področjih, Pojasnila k zgradbi slovarja, Označevalniki, Slovar, Seznam mineralov in Preglednica geoloških dob.

Pregled piscev slovarskih člankov in svetovalcev po področjih

Avtorji slovarskih člankov so: Danilo Ravnik - geofizika, Vida Pohar - geologija kvartarja,

Dušan Kuščer - hidrogeologija, Dušan Kuščer - inženirska geologija, Jože Duhovnik in Dragica Strmole - kristalografija, Jože Duhovnik, Dragica Strmole in Po-

lona Kralj - mineralogija, Jože Duhovnik - nahajališča mineralnih surovin, Jernej Pavšič - paleoekologija, Jernej Pavšič in Rajko Pavlovec - paleontologija nevretenčarjev, Vida Pohar - paleontologija vretenčarjev, Jože Duhovnik, Polona Kralj in Dragica Strmole - petrologija, Mario Pleničar in Rajko Pavlovec - regionalna geologija, Polona Kralj - sedimentologija, Danilo Ravnik - seizmologija, Mario Pleničar, Rajko Pavlovec in Jernej Pavšič - splošna geologija, Mario Pleničar, Rajko Pavlovec in Jernej Pavšič - stratigrafija.

Svetovalci: Simon Pirc in Jože Pezdič - geokemija, Aleksander Horvat in Tomaž Verbič - geologija kvartarja, Meta Dobnikar - kristalografija, Meta Dobnikar in Nina Zupančič - mineralogija, Simon Pirc in Matija Drovenik - nahajališča mineralnih surovin, Marija Štefančič -

paleontologija človeka, Nina Zupančič - petrologija, Stanko Buser, Marijan Poljak in Tomaž Verbič - regionalna geologija, Drago Skaberne in Aleksander Horvat - sedimentologija, Renato Vidrih - seizmologija in Stanko Buser - stratigrafija.

Avtorica seznama mineralov, ki so zajeti v slovarju in so zapisani tudi s kemijsko formulo je Dragica Strmole, avtorja priložene razpredelnice z razdelitvijo geološke zgodovine pa sta Jernej Pavšič in Marjan Grm.

Slovar je pripomoček za vse strokovnjake, ki se pri delu ali študiju srečujejo s področjem geologije, tako za strokovnjake kot tudi za študente geologije, geografije, gradbeništva, vodarstva, gozdarstva, agronomije, geodezije, arheologije in druge. Kot opredeljuje izdajatelj, je knjiga v oporo geologom pri iskanju ustreznih rešitev za jasno in razumljivo strokovno izražanje, negeologom pa pojasnjuje strokovne izraze in jih usmerja v njihovo pravilno rabo.

Po izidu slovarja se je pokazalo, da imajo strokovnjaki s posameznih področij geologije pripombe na razlago nekaterih izrazov, kar pa je razumljivo, saj vsi, ki najbolj poznajo izrazoslovje svojih specializiranih področij, niso mogli sodelovati pri nastajanju slovarja, ker bi se izid verjetno oddaljil še za nadaljnjih petdeset let. Vsekakor pa se bodo verjetno pripombe upoštevale v naslednji izdaji slovarja kot popravki ali dopolnila. Tako na primer nekateri termini iz krasoslovja v slovarju niso predstavljeni ali pa se njihova razlaga ne sklada popolnoma s Slovensko kraško terminologijo (Gams, 1973) in njihovo uporabo v novejši krasoslovni literaturi. Na primer, v slovarju ni pojma udornica, ki je že uveljavljen pojem v slovenski krasoslovni literaturi, za isti pojav pa je predstavljen izraz udorna jama, ki se v stroki ne uporablja. V slovenski strokovni literaturi se je uveljavil izraz brezstropa jama in ne brezstropna jama, kot je predstavljeno v slovarju.

Geološki terminološki slovar je vsekakor pomemben prispevek k razvoju geološke stroke in poenotenju strokovnega izrazoslovja, saj v veliki meri omogoča natančnost izražanja in nedvoumno sporazumevanje. Slovar stane 34 €.

Nadja Zupan Hajna

THE 25th SPELEOLOGICAL SCHOOL AND THE 8th GLACKIPR SYMPOSIUM "KARST AND CRYOKARST"; SOSNOWIEC- WROCLAW, POLAND

(19th - 26th MARCH 2007)

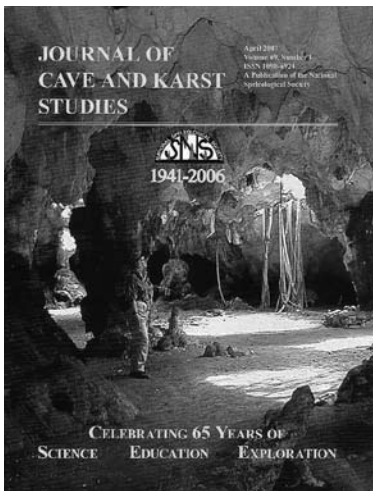
From 19th to 26th March the 25th Speleological School "Karst and Cryokarst" was organized by the Faculty of Earth Sciences, the Department of Geomorphology of the University of Silesia, Sosnowiec, Poland; the Zoological Institute, the University of Wrocław, Wrocław, Poland, and the Scientific Committee of the Niedzwiedzia Cave, Kletno, Poland with the scientific support of the Commission on Glacier Caves and Cryokarst in Polar and High Mountain Regions (GLACKIPR) of the UIS Karst Commission of the IGU. The Speleological School was established a few years after the discovery of the Niedzwiedzia (Bear) Cave in Kletno. The 25th Speleological School was dedicated to Professor Dr. Marian Pulina and Professor Dr. Teresa Wiszniowska, a paleozoologist from the University of Wrocław. During the School there was also unveiling of the commemorative plaque of Prof. Pulina at the Department of Geomorphology of the Faculty of Earth Sciences, University of Silesia in Sosnowiec. Professor Marian Pulina was a founder of Speleological School and co-founder of the Commission on Glacier Caves and Cryokarst in Polar and High Mountain Regions of the UIS and an active member of the Karst Commission of the IGU. From the very beginning, the School was international and multidisciplinary. It brought together classical karst and cave studies and the exploration of glacier caves. The 25th Speleological School was a joint meeting of UIS and IGU Commissions and also the 8th Symposium of GLACKIPR. There is a list of thematic sessions and field trips which were offered by this school: the relationships between glacial and karst systems; glacier caves and karst in recently glaciated areas; drainage systems in glaciers and karst - analogies and differences; cryokarst - definitions, analogies and relationships with carbonate karst; chemical denudation rates in glacier-covered and ice-free karst basins; evolution of karst under glaciation, with special reference to continental glaciations and permafrost; hydrothermal activity and its influence on karst evolution in glaciated areas; cave sediments, fossil cave fauna and human traces in caves as records of environmental changes in the past, with special reference to the Pleistocene glaciations.

Programme of the meeting was separated into three parts. **Part A**, March 19-21 2007 was organized as a field trip and session in Kraków-Częstochowa Upland (Częstochowa Plateau) and was dedicated to evolution of karst under glaciations, hydrothermal activity

in the past, cave sediments, fossil cave fauna and traces of man in caves. Excursions visited area of Kroczyce Hills (Podlesice - Łysak Hill - Popielowa Hill - Posrednia Hill - Zborów Hill (Cave in Kroczyce) of the Kroczyce Hills (light is necessary); and the northern part of the Częstochowa Plateau (karst and caves in the contact zone with the Odranian/Saale Glaciation ice-sheet, stops in Siedlec quarry - Towarne Hills - Kusięta - Sokola Hill in the area of Olsztyn). **Part B**, March 22-23 2007, was dedicated to main scientific sessions of the 25th Speleological School and 8th GLACKIPR Symposium at the Faculty of Earth Sciences, University of Silesia in Sosnowiec. There were lectures and posters of different fields of karst and glaciokarst research. Abstracts and Guidebook for the excursions were published before the meeting; P. Socha, K. Stefaniak and A. Tyc edited publication. **Part C**, March 24-26 2007, was separated in two parts, to session at the University of Wrocław and to field trip and session in the Niedzwiedzia Cave in Kletno (Sudety Mts.). Field trip to Kletno and Jaskinia Niedzwiedzia was dedicated to karst phenomena of the Klesnica Valley, karst and caves in marbles, cave climate, fossil fauna with special reference to cave bear, old fluorite and uranium mining area; and field trip to the area of Radochowska Cave to karst hydrology, cave archaeology and fossil fauna.

School was again very successful, there were 132 participants from Canada, China, Czech Republic, France, Germany, Italy, Moldova, Norway, Romania, Russia, Slovakia, Slovenia, Spain, Ukraine and Poland. 41 of the participants were PhD and undergraduate students from Poland, Czech Republic, Romania and China. Slovenia was presented by Andrej Kranjc, also a president of the IGU Karst Commission, Maja Kranjc, Jurij Kunaver, Andrej Mihevc, Tadej Slabe and Nadja Zupan Hajna. A large party of researchers from Slovenia shows the long tradition of collaboration between Poland and Slovenia in the field of karst research.

Nadja Zupan Hajna



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