ACTA CARSOLOGICA	XXVII/2	8	115-138	LJUBLJANA 1998

COBISS: 1.08

INTERACTION BETWEEN A CAVE SYSTEM AND THE LOWERING KARST SURFACE CASE STUDY: LAŠKI RAVNIK

JAMSKI SISTEMI IN ZNIŽUJOČE SE POVRŠJE KRASA VZORČNI PRIMER: LAŠKI RAVNIK

FRANCE ŠUŠTERŠIČ[1]

[1] University of Ljubljana / Department of Geology, Aškerčeva 12, SI-1000 LJUBLJANA, SLOVENIA
E-mail: france.sustersic@ntfgeo.uni-lj.si

Prejeto / received: 31. 10. 1998

Izvleček UDK: 551.44(497.4)

France Šušteršič: Jamski sistem in znižujoče se površje krasa; vzorčni primer: Laški Ravnik

Podan je inventar denudiranih globoko freatičnih jamskih oblik, ki se danes pojavljajo na kraškem površju v Laškem Ravniku (vzhodno od Planinskega polja). To so denudirani delno izprani kanali, denudirani z ilovico popolnoma zadelani kanali, zaplate ohranjenega polnila izbrisanih jam, konglomerat in siga. Možen izvor polnil je v porečju Cerkniščice. Organizacija jamskega spleta se sklada s Ford-Ewersovim modelom in nakazuje pravilnost nekaterih spoznanj R. Curla, S.Worthingtona in D. Loweja.

Ključne besede: speleogeneza, kraško površje, denudacija, jamski sistem.

Abstract UDC: 551.44(497.4)

France Šušteršič: Interaction between cave systems and the lowering karst surface; case study: Laški Ravnik

An inventory of denuded and exhumed deep phreatic cave forms that have been detected on the karstified surface of the Laški Ravnik (east of Planinsko polje, Slovenia) is presented and described. Features observed include denuded completely-filled channels, washed-out channels, accumulations of cave loam (originating from caves that are now completely destroyed), conglomerate and flowstone. The source area for the sedimentary infills might be the Cerkniščica river catchment. Cave patterns revealed by the study fit well to aspects of the Ford-Ewers' cave development model, and also indicate the validity of some of the observations made by R. Curl, S. Worthington and D. Lowe.

Key words: speleogenesis, karst surface, denudation, cave system.

INTRODUCTION

It appears to be self-evident that steady denudational activity in the karst will eventually "bring" endokarstic phenomena to the surface. In fact, most textbook authors mention "denuded underground phenomena" explicitly among their standard inventory of surface karst features, but their approach is one of passive recording that does not tend to promote active research designed to extract wider conclusions. Most authors agree that so-called "collapse" dolines are cave chambers that have propagated to the surface. A few textbook authors (such as White, 1988) and some more recent workers (Šušteršič, 1994; Klimchouk, 1995) share D'Ambrosi's (1960) opinion that (at least some) "solution" dolines represent vertical shafts that have somehow been transformed[1].

Nevertheless, these examples cover only a small part of the full suite of endokarstic phenomena. It is as if a rule can be read between the lines, that all other phenomena become undetectable long before they emerge at the surface, and this rule appears to have been accepted widely. However, belief in such a rule misleads its adherents, taking them far away from considering the idea that details of the organisation of underground transmission systems can be exposed and studied at the land surface.

During preparatory work for the construction of the motorway between Divača and Sežana, a horizontal roofless cave about 200m long was found (Mihevc, 1996). It was filled completely with still recognisable cave sediments, and the infill was later cleared. Re-inspection of earlier infrared aerial photographs revealed that the course of this passage - and, by analogy many others in the neighbourhood - was clearly recognisable. Further field indicators of buried caves were soon discovered, and what was previously viewed as a mere curiosity became an efficient tool for use in karst studies. Both the methodology, which spontaneously acquired the familiar name "surface caving", and the knowledge deriving from its use have since evolved in several ways.

A. Mihevc's (o.c) paper turned out to be more than prophetic, being followed by discovery of several kilometres of "surface" extensions of the Škocjanske jame (Mihevc, 1998). In the introduction of the (1996, 66) paper, he says: *"Though the roof-less cave is somehow no longer a cave, but more of a trench, it is worthy of scientific interest. Whereas a number of speleologists have recently turned their interests towards the study of the processes that bring about the very beginning of cave formation, such channels display the other extreme of speleogensis. They demonstrate either the transformation of a cave into a surface karst relief feature, or even the eventual complete removal of the cave. Their recognition helps to explain the existence of flowstone formations and the occurrence of silicate sand and gravel at the land surface, and reveals the essence of terrain lowering."*[2]

Though in contact with A. Mihevc and aware of his findings, the present author adopted a quite different approach. Detailed geomorphological mapping of the karst surface in Laški Ravnik (at 1:5,000 scale) began in 1994, with the unambitious intention of providing a wider background for detailed study of solution dolines in the transect from Pokojiše to Grčarevski vrh (Šušteršič, 1987; 1994-b). Based on experience gained studying the Najdena jama - Vranja jama - Jama Kloka cave

[1] *The last four years A. Mihevc (1995, 1996, 1998-a, 1998-b) and his co-worker's (Šebela, Mihevc, 1995; Mihevc, Zupan Hajna, 1996; Cucchi, Mihevc, Ferarese, Sauro, 1997; Mihevc, Kranjc, 1998; Mihevc, Slabe, Šebela, 1998) papers are an exception, however.*

[2] *Translated by F. Šušteršič .*

system (Šušteršič, 1994-a), the presence of a number of outcrops of denuded cave channels became apparent. With gradually increasing knowledge of the denuded cave features the author was obliged to switch from the mere recording of isolated denuded underground phenomena to carrying out systematic research into a complete cave system. During the past two years, many interesting "roofless caves" have been mapped at 1:250, or even 1:100 scales, and studied in detail.

The caves studied by A. Mihevc and his colleagues (see above) are predominantly epiphreatic, generally large, rich in flowstone and - though filled with sediments - relatively easy to identify. In Laški Ravnik, the features currently accessible were originally deep phreatic, oblique (reflecting the dip of the enclosing strata) and relatively small, with only limited, localised, flowstone. Where washed clean, the channel walls are seen to be modified to some extent by small-scale spalling. Fortunately, the karst surface, though forested, is not extensively soil covered, and this facilitates the mapping process.

To identify such objects and sediment occurrences as cave features, wide practical experience in speleology is vital, together with knowledge of the ideas of D. Ford and R. Ewers (1978) and newer speleogenetic theories (Worthington, 1991; Lowe, 1992). In turn, field evidence has verified various aspects of the cited theories, in a way that can be summarised by the statement that pre-existing concepts related to fluvial terraces have had to be replaced by the logic of interconnected vessels.

Oral presentation given in 1997[3] provided general information on the current state of the art. Later, the mapping project became more ambitious, with the intention of delimiting the full extent of the previously completely unknown denuded maze cave system, and gaining insight into its spatial organisation. Currently the area mapped has been nearly doubled, and a rich collection of information has been assembled.

[3] *Fifth International Karstological School, Postojna, June 1997.*

Fig. 1: Distribution of directly detectable denuded channels in the Laški Ravnik. (Note: until recently only the features included within this group would have been recognised and mapped more or less completely. The presence of other, less obvious, types of feature was unrecognised when mapping began, and the areas that were mapped earliest should now be re-examined.)
1. Openings of phreatic tubes. All are choked after some metres;
2. Small collapse features (<3m), evidently continuing to a choked tube;
3. Segments of (sub-)vertical tubes, formed under phreatic conditions;
4. Denuded cave passages, filled with loam and other sediments;
D. Dolomite.

Sl. 1: Prostorski razpored neposredno razpoznavnih jamskih kanalov v Laškem Ravniku. (Od vsega začetka so bili jasno poznani samo objekti te skupine. Znanje o ostalih je raslo skupaj s kartiranjem in zato bo potrebno začetkoma kartirana območja pregledati še enkrat).
1. Žrela freatičnih kanalov. Vsi so po nekaj metrih zatrpani;
2. Manjši udori (<3m), ki se očitno nadaljujejo v zatrpan kanal;
3. Odlomki skoraj navpičnih kanalov, nastalih v freatičnih pogojih;
4. Denudiran jamski rov, zapolnjen z ilovico ali drugimi sedimenti;
D. Dolomit.

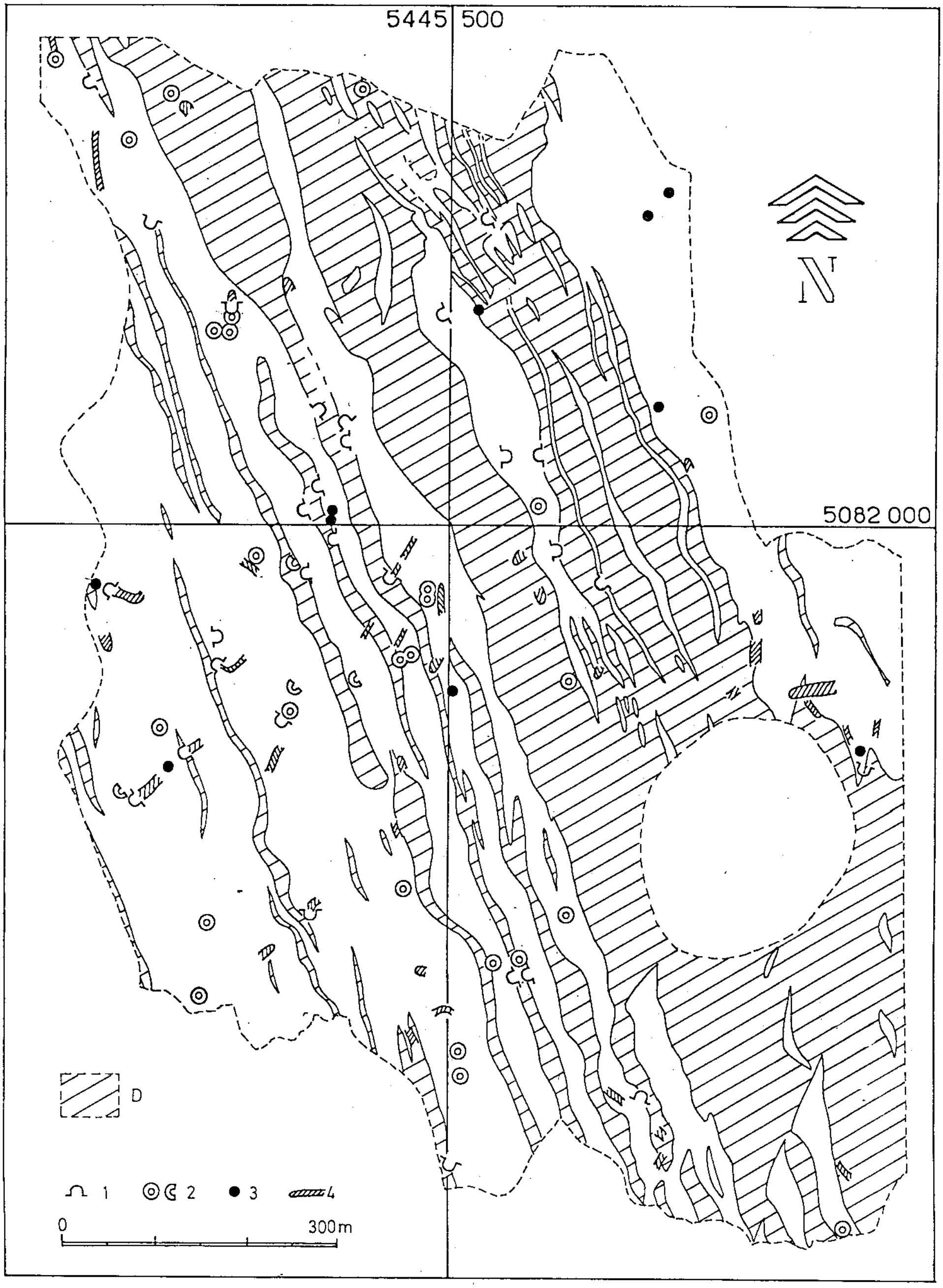

Fig. 1 - Sl. 1

This paper is primarily intended to document the presently known inventory of denuded cave-derived phenomena that now form part of the surface karst in the mapped area. Secondarily, some indications of the system parameters are listed, as these impinge in several ways upon fundamental notions concerning karst drainage systems. It is now apparent that the approach described provides better explanations of several long-recognised karst phenomena, but the full extent and implications of this enlightenment are yet to be reached. Further research, in several directions, is in progress.

GENERAL INFORMATION ABOUT LAŠKI RAVNIK

The Laški Ravnik[4], about 3km north-east of the Planinsko polje, forms part of a low-relief corridor, known generally as Ravnik by local people. Ravnik is about 18km long and 1 to 3km wide. It was previously explained as being the dry valley of a karstified river, but recent research showed this explanation to be barely tenable (Šušteršič, 1996-b). The area is generally flat and extremely rich in solution dolines (Šušteršič, 1994-b). Some of the main streams of the underground Ljubljanica system must flow beneath the area, but no active stream cave has yet been found among a number of short fragments of evidently phreatic origin.

Structurally the area is a monocline, with beds dipping at 25° to 30° towards the west-southwest. The oldest beds, exposed at Borovnica, comprise Middle Triassic clastic rocks and dolomites. These are overlain by the c.6,850m-thick Dinaric carbonate sequence, topped in turn by Eocene flysch deposits on its western side. The area investigated coincides with the contact between the Jurassic and Cretaceous rocks. Early mapping revealed a c.300m-wide outcrop of coarse-grained secondary dolomite at this point, and this was claimed to be the youngest Jurassic unit. Recent

[4] *See also Introduction to J. Pezdič, F. Šušteršič, M. Mišič (1998)!*

Fig. 2: Structure 17 - d / 2, Ravnik.
1. Loam (no bauxite pebbles observable at the surface);
2. Loam (bauxite pebbles visible at the surface);
3. Presumed collapse material (slabs);
4. Slabs detached from the parent rock but presumed to lie close to their original position;
5. Deatched slabs with large gaps between them;
6. Presumably larger blocks, derived by in-situ break-up of the cave ceiling, and supported by the cave fill until it was washed away.

Sl. 2: Struktura 17 - d / 2, Ravnik.
1. Ilovica (na površini ni najti boksitnih prodnikov).
2. Ilovica z boksitnimi prodniki na površini.
3. Domnevno podorno skalovje.
4. Bloki, odluščeni od podlage vendar ne bistveno premaknjeni..
5. Posedli bloki z velikimi medprostori.
6. Bloki, nastali po razpadu jamskega stropa, ko večji kosi niso odpadli ampak so "sedeli" na polnilu, ki ga je deževnica izpirala iz podlage.

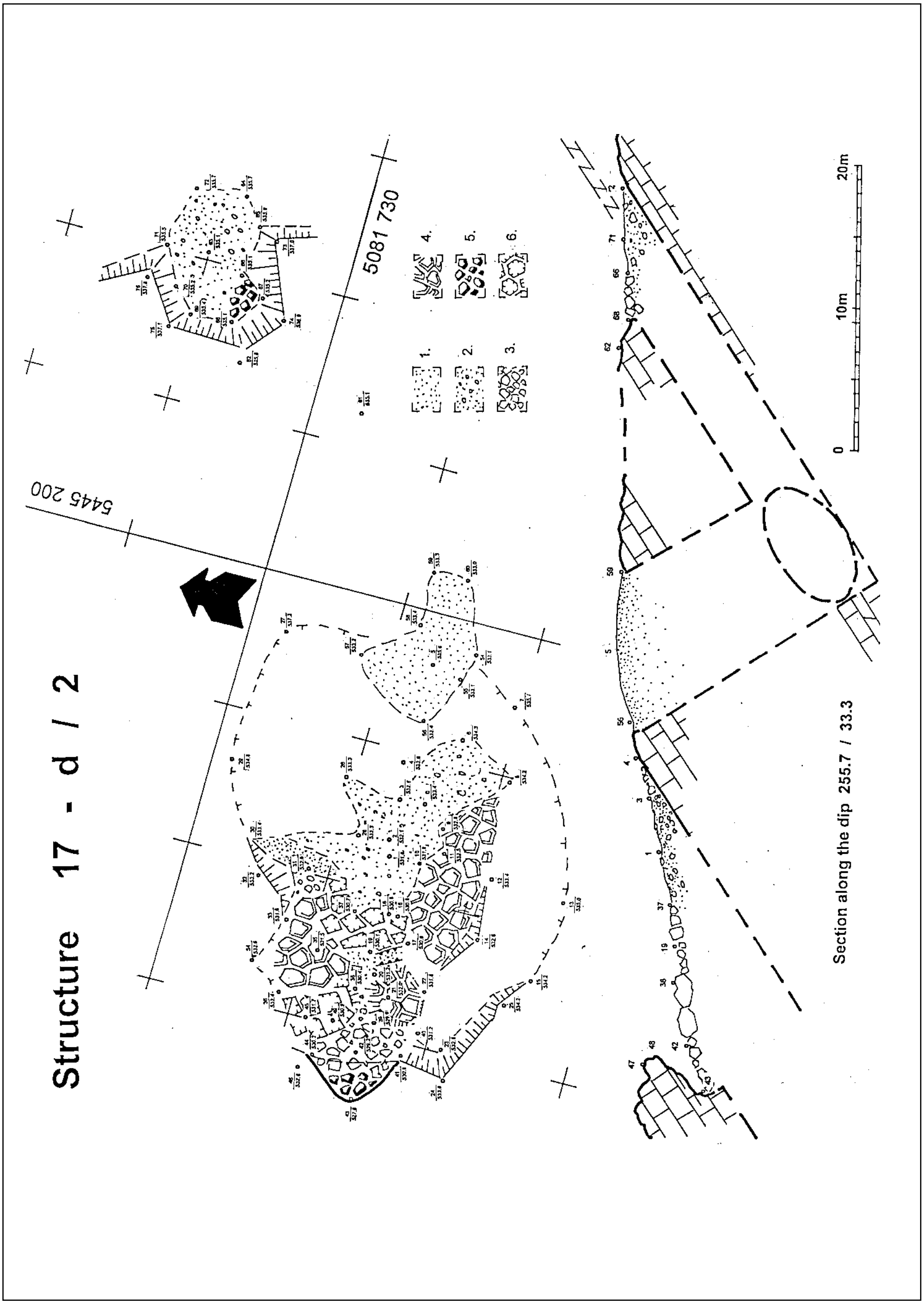
Structure 17 - d / 2
5081 730
5445 200
1.
2.
3.
4.
5.
6.
0
10m
20m
Section along the dip 255.7 / 33.3

Fig. 2 - Sl. 2

Fig. 3: Stages in the gradual decay of an inclined, sediment-filled, phreatic channel. (Note that the limits of the "phases" illustrated are more or less arbitrary.)
A. The original phreatic channel, not yet reached by the zone of influence of surface weathering.
B. The sediment-filled channel is intersected by the surface weathering zone. Breakdown of the channel ceiling takes place and large isolated blocks of the parent rock are supported by the fill.
C. The passage ceiling and the upper parts of its walls are removed as surface downcutting continues. Washing-out of sediment is somewhat faster than the general surface lowering, and a small depression develops on the surface. Large, insoluble clasts gradually concentrate in the floor of the depression.
D. Most of the cave walls have been removed, together with most of the former infill. Fragments of decayed flowstone and insoluble pebbles are preserved along the line of the former cave floor.
E. Both the cave and its parent rock have been totally denuded. A slight secondary depression persists for some time within the new land surface. Insoluble pebbles in its bottom are the only evidence of the former presence of the cave. Remnant concentrations of loamy infill are preserved only locally, within isolated pockets.
P. Contour of denuded cave channel.
S. General level of the undisturbed surface in the neighbourhood.

1. Weathered parent rock. Note that brown forest soil is not particularly evident between the clints.
2. Intact parent rock. The joint pattern is conjectural.
3. Basal fill, comprising loam with bauxite pebbles (marked as rounded black patches).
4. Flowstone, supported by loam.
5. The direction of the view shown in Fig 4.

Sl. 3: Postopen razkroj denudiranega poševnega kanala. (Posamezne "faze" so bolj ali manj poljubne.)
A. Kanal v "prvotnem" stanju. Cona površinskega preperevanja ga še ni dosegla..
B. Cona površinskega preperavanja je dosegla kanal. Strop se je razkrojil v posamezne bloke, ki "plavajo" na polnilu.
C. Strop in zgornji predeli sten so izginili. Ker je izpiranje nekoliko hitrejše od splošnega zniževanja površja, nastane manjša globel. Na dnu se postopoma zbirajo večji netopni prodniki.
D. Stene jame so, enako kot večina polnila, izginile. Na njenem dnu se nabirajo ostanki sige in netopni prodniki.
E. Jama in okoliška kamnina sta popolnoma izginili. Drugotna poglobitev še nekaj časasa vztraja na površju. Edini priča nekdanje jame so prodniki v njenem dnu. Zadnji preostanki ilovnatega polnila so se ohranili v žepih.
P. Obris denudiranega jamskega kanala.
S. Približna višina neprizadetega okoliškega površja.

1. Razkrojena matična kamnina. Rjava gozdna prst med bloki ni posebej označena,
2. Nedotaknjena matična kamnina. Vzorec je izmišljen.
3. Bazalno polnilo - ilovica z boksitnimi prodniki (okrogle lise).
4. Siga, ki "plava" v ilovici.
5. Smer pogleda slike 4.

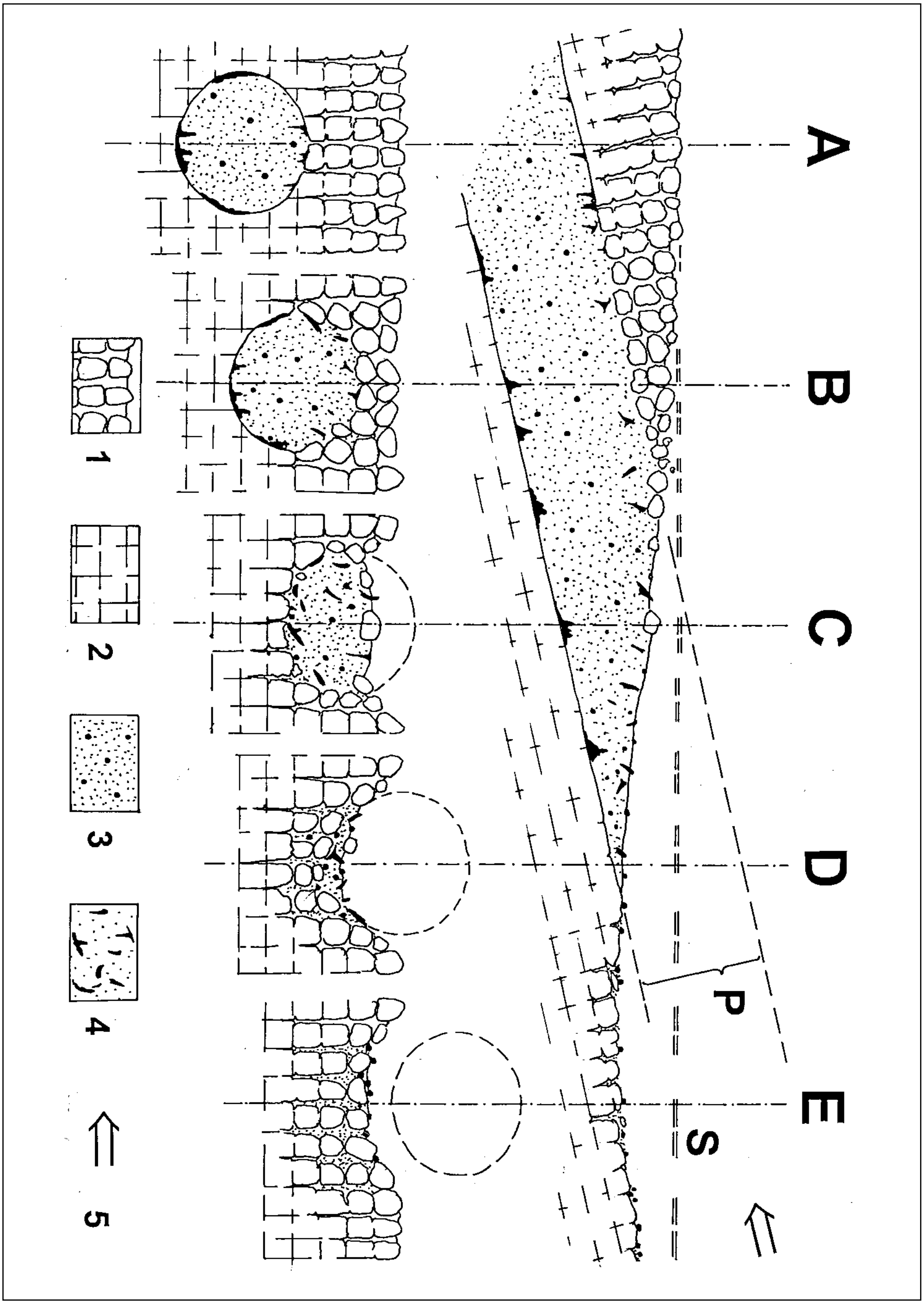

Fig. 3 - Sl. 3

fieldwork has revealed that there is not a single dolomite package, but an interfingering of wider or narrower dolomite/limestone stripes (Fig.1), so that the position of the stratigraphical boundary remains vague. However, this consideration is of only secondary importance to the discussion as a whole.

The low-lying Ravnik corridor runs parallel to the well-known Idria Fault, which lies about 2km to the east, but this does not appear to be greatly significant. On the other hand, two lines, until recently only partly recognised as major crush zones, run parallel to both sides of the Ravnik. Some displacement is evident along the north-eastern side, but the amount and direction are not yet confirmed. Additionally, the whole mapped area of Laški Ravnik is crossed by a swarm of sinistral strike-slip faults, running about 150m apart in a north-north-westerly direction. Evidently, these fractures formed in response to regional, dextral strike slip movement between the Idria Fault to the south-west, and a parallel fault of smaller displacement, perhaps the one lying along the north-eastern margin of Ravnik (Šušteršič, 1998).

Previous statistical study of the known cave distribution within the Ljubljanica sinking river basin (Šušteršič, 1996-b, Fig. 5) showed a slightly increased cave density in the general area of Laški Ravnik, but no obvious distinctive peak. At that stage it seemed reasonable to assume that the increased cave density merely reflects the fact that the main underground streams of Ljubljanica pass beneath. Subsequent study revealed a previously unknown cave system, with a morphology that could hardly be attributed to development by water from the present Ljubljanica. It appears that the modern river simply encountered and made use of earlier underground channels that formed under totally different conditions.

Ravnik is entirely covered by dense coniferous forest. Though a 1:5,000 scale map derived from airborne survey exists, it is useless as a base for detailed mapping. Thus, all of the footpaths, and most animal trails were surveyed on the ground using tape and compass, to obtain a baseline framework for future mapping. Positions of some 50 survey stations were fixed by placing iron markers, and the total length of the surveyed traverses amounts to about 50km.

THE DENUDED KARST SYSTEM IN THE LAŠKI RAVNIK

General remarks

As in the case of the classical Karst, best and most recently described by A. Mihevc, T. Slabe and S. Šebela (1998), denuded endokarstic structures within the parent rock and the sediments deposited within them have played equally important roles. Two differences must be emphasised. First, in the case discussed here, the denuded system is completely phreatic. Secondly, the enclosing strata (and hence the cave's guiding inception horizons) dip at up to 30^{o} and, consequently, insight into the system's 3-D spatial organisation is possible.

The set of "derived" denuded underground karst phenomena now detectable at the surface is much larger then previously believed. In suitable circumstances even some of those that are impenetrable to humans, and more or less inferred until now, became accessible to detection and study. Even more - because more abundant information can now be obtained - it turns out that the organisation of the cave system is far more structured, and much less chaotic, than was ever previously imagined. Last, but by no means least, application of "surface caving" has led to the identification of some previously unsuspected features.

Fig. 4: A down-dip view of a denuded phreatic channel. The moss-covered layer directly beneath the figure is a dolomite bed about 0.7m thick. Its lower boundary plane is presumed to be the inception horizon that guided development of the former cave passage.
Sl. 4: Pogled na toneči denudirani freatični kanal. Mahovita skala desno pod človeško postavo je okrog 0.7 m debela dolomitna plast. Začetni horizont je domnevno na njeni spodnji strani.

Fig. 5: Characteristic outcrop of conglomerate. Note the hollowed-out dolomite pebbles.
Sl. 5: Značilen izdanek konglomerata. Jasno so vidni izvotljeni dolomitni prodniki.

Fig. 6: Typical "wall" flowstone preserved in a denuded cave.
Sl. 6: "Stenska" siga v denudirani jami.

Fig. 7: A typical example of "aureole" flowstone. Note that it is surrounded by bedrock.
Sl. 7: "Aureolna" siga. Vsenaokrog je živa skala.

Directly detectable channels

Except for some vertical vadose shafts, which appear to be very young, all of the cave channels identified to date (Fig. 1) are wholly phreatic in origin and all of them are filled with sediments. Thus, among the "directly detectable" channels, dominated by overhangs or short fragments, a number of dipping caverns, choked farther down by sediments, have been recorded. Because the strata are relatively steeply dipping, a wide variety of channel sections appears at the surface. Though surface weathering, especially frost shattering, has affected them all to some degree, none displays any sign of epiphreatic shaping. Bedding plane channels dominate, while phreatic jumps, or lifts, in various stages of disintegration are not uncommon. "Horizontal" channels running parallel to or at the surface are rare. Denuded caves of trench-like form that would pass into true cave channels have not been found within the mapped area - though they do exist nearby.

Thus, a significant number of features exist, that have been partly washed clean in relatively recent times. Structure 17 - d / 2 (Fig. 2) is just one among the largest examples, and the number of smaller ones increases in proportion to their decreasing dimensions. However, only channels larger than 0.5m have been detected and recorded during field mapping - the number of smaller ones may be even greater than the number of those identified to date.

All of the surface features derived from phreatic channels had formed essentially along bedding planes. Joint guidance might have had a local role in a few cases - but these appear to be exceptional. Channel directions vary widely, but most appear to be oriented down the dip. However, this just field impression.

Less numerous overall, but still easily observable, are relics of phreatic jumps, or lifts. They are approximately vertical and their openings resemble small solution dolines. As there are no specific features that allow the openings to be distinguished from infilled vertical shafts when viewed in isolation, all identifications to date are based on secondary criteria. So, it is quite probable that they are even more numerous than the present estimates suggest. Finally, surface remnants of passages running along the strike, are very rare, and they appear to be exceptions.

Some washing out and redistribution of the sedimentary fill commonly follow disintegration of the cave roof and walls. If experience from various sites is fused together, a logical string of features characteristic of interaction between the lowering karst surface and underlying, sediment-filled caves can be established (Fig. 3). Several field examples of most stages of the interaction exist in Laški Ravnik but, in order to make the progression more general, information about the occurrence of flowstone beneath loamy sediment is introduced from another location.

Once the sediment has been removed denudation starts from the bottom of the former cave and acts preferentially on the adjacent rock. So, for a significant time, the "negative volume" of the former cave is imprinted into the formerly underlying rock, until chaotic weathering finally erases its effects completely. Such a progression appears to be supportable logically, but it is difficult to eliminate alternative interpretations. However, this explanation appears to be strongly indicated and supported in a relative few locations, where the inception horizon is visible close to such a depression (Fig. 4).

Fine-grained cave sediments

The structures discussed above have been partly washed clear of sedimentary fill and are thus relatively easy to recognise as cave remnants. More commonly, deposits of cave infill remain virtually untouched as the cave walls disintegrate. For many years these occurrences were interpreted as surface sediment, representing material transported by some supposed pre-karstic river. Only more recent detailed study has confirmed that it is cave sediment in either its primary or a secondary position.

The most widespread fill material is brownish loam with minor admixture of relative large oolitic bauxite pebbles (derived from the Triassic Carnian beds) and coarse clasts of black chert. Such sediment appears to have filled the original cave system when it was completely water-filled, because no flowstone is found on the underlying cave walls. As it is nearly ubiquitous, and lies beneath any other preserved cave sediment, it is referred to as *basal fill*. Grain size distribution does not suggest normal fluvial loading and deposition. Instead, it appears that a mudflow, capable of lifting and transporting relatively large bauxite clasts, filled the system.

At two locations, exposures of channels about 10m wide were found, filled with finely laminated, poorly cemented silt, resembling varves. This sediment appears to be younger than the *basal fill*, but was also deposited when the caves were water-filled.

At one site, partly-cemented carbonate sand, including quartz crystals, was found in a pocket that was possibly a former cavern. Its significance within the system as a whole is currently unknown.

If all of the parent rock around a previously filled cave were disintegrated, the insoluble sediment would remain on the subsequent land surface, where it would gradually be dispersed by continued terrain lowering. At some localities it is still possible to distinguish the resultant pattern by observing concentrations of bauxite pebbles and chert on the modern land surface. Most such concentrations can be related to a nearby outcrop of a denuded cavern, or at least to a recognisable inception horizon. Such features are referred to as *phantom caves*.

Ongoing terrain lowering would increase sediment dispersion and possibly re-concentrate any insoluble pebbles into newly formed pocket deposits. Such occurrences are referred to as secondary.

Coarse-grained cave sediments

Outcrops of conglomerates, deposited in now denuded caves, are much less common. Clast size varies greatly - from coarse sand grade to large pebbles a few centimetres across (Fig. 5). They are predominantly of Upper Triassic dolomite (which might originate from the same area as the oolitic bauxite discussed above), with an admixture of Jurassic limestone clasts that are probably more local. Small quantities of bauxite and chert occur too, but it is yet not possible to say whether they were brought in as part of the stream load or simply admixed on the spot. Coarse rubble, originating from the channel roof or walls is present locally.

Generally, the structure of the conglomerate displays such typically alluvial features as graded bedding and laminated sedimentation. The matrix, which is loamy, ranges from being barely present to comprising more than 70% of the rock. In the latter case large pebbles are found “floating”, supported by the matrix. Most of dolomite pebbles were hollowed during vadose diagenesis. The conglomeratic deposits may lie on or beneath flowstone, or flowstone layers can occur sandwiched between beds of conglomerate. This indicates that the conglomerates were deposited at a relatively late stage, when system development was largely under vadose conditions.

These conglomerates are generally as resistant to weathering as the adjacent bedrock. In several areas conglomeratic masses have been dissected to form clints and grikes in the same way as the neighbouring rocks. In some situations the conglomerate is more resistant, and stands proud of the surrounding parent rocks. Typically, the conglomerates are more prone to being covered by mosses than are the adjacent solid rocks.

Conglomerate blocks are commonly found "floating" within the *basal fill*. Thus, for some time, it was believed that the loam originated from disintegration of conglomerate. More detailed study has shown that though some of these blocks are corroded, they are actually fluvial sediment that was deposited (and further cemented) in partly washed-out old systems, where the *basal fill* was emplaced much earlier.

Flowstone in the denuded caves

There is little to be said about the flowstone. It is evidently younger than the *basal fill*, but contemporaneous with the conglomerate, in the sense that dry periods of flowstone sedimentation alternated with, perhaps catastrophic, flood events, when gravel-laden water rushed into dry caves. However, these parts of the system must have been partially washed out earlier, by either percolation or vadose water.

The completely recrystallised flowstone is of various types, ranging from nearly pure, glassy calcite, to heavily clay-stained formations. Most is in the form of wall-flowstone or half-stalactites (Fig. 6). Flowstone cave bottom crusts are also found, whereas true stalagmites appear to be absent. Most flowstone is found associated with conglomerate, with only a few exceptions where flowstone crusts survive on the walls of nearly completely washed-out caverns, making the type of loam difficult to determine.

Much of the flowstone appears either within confirmed former caves or in situations where the presence of a former cave is at least strongly implied. However, some occurs in fractures and other narrow openings, which may be completely filled with flowstone. Without exception these occurrences are no more than 20m from a larger (at least 5m) cavern. This flowstone variety has been described as *"aureole flowstone"*, and its origin is still a matter of discussion (Fig. 7). One possible explanation is that it was deposited at relatively great depth beneath the surface, where the rock mass is relatively poorly ventilated. Saturated percolation water in small voids could generally not give up its surplus CO_2, except where close to larger, better ventilated, caverns. Consequently, the aureole flowstone is deposited only in these situations.

Determination of the age of the flowstone deposits in denuded caverns is clearly beyond the reach of the U-Th series method, and no attempt to measure their date(s) of emplacement has yet been made.

Small collapse dolines

There appear to be two types of collapse doline in the Ravnik, as was perhaps first pointed out by F. Šušteršič (1973, 75). By their dimensions the "small" ones perhaps accord with the idea of sudden collapse of a cave roof, while the "large" ones must subsequently have been enlarged extensively (Šušteršič, 1998). The same fact was established on the karst near Divača by A. Mihevc (1998-b, 72), who numbered them among the surface karst phenomena that originating from denudational lowering of the surface. Within the Ravnik area only one of this type has so far been identified.

ABOUT THE LAŠKI RAVNIK CAVE SYSTEM IN GENERAL

The exhumed cave segments detected in the Laški Ravnik are quite clearly of deep phreatic origin. Thus, an opportunity exists here to estimate the extent of ranks of channels within a single tier. Detailed mapping to collect information from virtually every possible outcrop has covered only about 1.5 km^2 and within this area no indication of any limit of the flow corridor was found. An area of several km^2 was relatively well visited and at least the presence or absence of the larger cave outcrops was established within it. Within its limits, the involvement of rocks with a vertical range[5] of several hundred metres is evident, as is the fact that some geological structures function as distinct borders between blocks where the *basal fill* is present or absent. The Idria Fault in particular, on its south-western side, provides a very clear-cut divide. This part of Slovenia is generally well enough known to allow the statement that this sediment is not ubiquitous but is restricted to the Ravnik and some neighbouring areas. However, the extent of the denuded phreatic channel occurrences and the extent of the *basal fill* may not overlap completely. Nevertheless, the concept and dimensions of a flow corridor, proposed by S. Worthington (1991), appear to be quite well supported.

The succession of processes affecting the area has already been described, and only a general overview is re-presented here. It is self evident that the set of phreatic channels is the oldest feature, probably dating back as far as the oldest cave systems in the neighbourhood, and subsequently affected by Idria Fault tectonics. (Šušteršič, 1996-b). The *basal fill* must have been deposited within the channels when conditions were relatively uniform across a wider area, when the system was still phreatic. The vertical range[6] of these sediments, which exceeds 100m, supports this idea. The length of the time gap between this phase and the last phase of partial outwash remains unclear, but it could be very long.

At a time when conditions were to some extent similar to today's - when at least the catchment area boundaries were comparable to modern ones - flowstone formation and conglomerate sedimentation took place, apparently under vadose conditions. Conglomerate-filled caves are exposed in the slopes of the most of the large collapse dolines, which suffered their essential transformation during the last glacial episode (Šušteršič, 1998). Unfortunately, outcrops of conglomerate have not yet been identified in the elevated flanks of the Ravnik lowlands, as the *basal fill* was, and it is not possible to establish the vertical extent of the sedimentation. Nevertheless, the information from the large dolines suggests at least 10 to 20m.

The position and significance of the three "exceptional" sediment types within this scheme remains unclear. Some indications exist that at least the varved loam is younger than the *basal fill,* but older than the conglomerate.

The origin of the various sediments is less problematical. A source for the dolomite sand and gravel in the upper part of the Cerkniščica river appears to be quite plausible, especially as even today such sediment makes up the bulk of the Cerkniščica's load. The outcrop of Lower Triassic, Raibl Formation, oolitic bauxite in the upper part of the Cerkniščica basin is also well known. However, if considering the great age of the *basal fill*, and average rate of denudation (65m Ma^{-1}; Gams, 1966), great changes in the relief, catchment areas and general transport conditions, may be

---

[5] *In the sense of stratigraphic thickness, i.e. perpendicular to the strata.*
[6] *Meant in the direction of the Earth radius.*

assumed to have taken place. Thus, the source of the bauxite might have been elsewhere, and now completely removed by erosion.

SOME INDICATIONS OF DEEP PHREATIC SYSTEM ORGANISATION

The presence of many smaller channels suggests that at least some information about the 3-D organisation of the flow corridor might be extracted. Though more than 100 surface occurrences have been noted, their dimensions were not estimated precisely enough to allow fair statistical analysis. Nevertheless, there appear to be strong indications that the phreatic maze is fractal, as R.L. Curl (1986) concluded elsewhere on the basis of the statistics of some American caves, and the subject awaits further research.

It appears that larger channels (more than 5m wide) are not distributed uniformly, but instead they seem to exist as pairs or triplets. This phenomenon is not completely unknown, as several examples are exposed in the walls of the limestone Alps. For the moment, however, its explanation is beyond the reach of author's knowledge.

Detailed inspection of Fig. 1 reveals that although the area has been strongly reworked by denudation it remains possible to observe that most of the phreatic tubes lie within or close to either the upper or lower limestone/dolomite contact. At some locations this is clearly visible to the naked eye in the field. Elsewhere the dolomite band is too narrow to be recognised at first glance, though detailed search within the neighbouring rock has nearly always proved its existence. As previously described (Šušteršič, 1997), there is some evidence that the lower contacts of dolomite layer within the limestone sequence are in some way more favourable. In this way D.J. Lowe's (1992; Lowe and Gunn, 1997) inception horizon hypothesis appears to be proved on a large scale, especially the explanation offered by trans-bedding contrasts. In Laški Ravnik, J. Pezdič, F. Šušteršič M. Mišič (1998) proposed an explanation based upon the re-calcitisation of dolomite, but this is just one possibility.

Most of the channels are related directly to the trans-bedding contrast, but a significant number of others also lie in their close neighbourhood. Detailed inspection revealed that phreatic channels may locally leave the inception horizons, probably due to the presence of a permanent or temporary obstacle, for a short distance and then return to the original bedding plane (Fig. 2). This has resulted in development of a number of short phreatic jumps that are generally related to such situations. The conclusion is that inception horizons may be most important during the early speleogensis, while later secondary effects make them locally less attractive.

ACKNOWLEDGEMENTS

This work could not have been carried out without the help of my keen students, who searched among the densest forest for new exposures. Several years of ongoing discussion around the tea table with my friend Andrej Mihevc have clarified many obscure details, and helped me to apply the "surface caving" concept to various more difficult situations than those at the original sites on the Classical Karst. Theoretical support of another friend, David J. Lowe was indispensable, as was his help in smoothing the English translation of the present text. Many thanks to all.

REFERENCES

Brenčič, M., 1993: Cave breakdown processes in caves, illustrated in the cave Koševelc on Ljubljanski vrh (in Slovene, English summary[7]). Naše jame, 35 (2), 25 - 31, Ljubljana.

Cucchi, F, A. Mihevc, F. Ferarese, U. Sauro 1997: Classical Karst guide for the excursion. Meeting IUS 1997 in Italy, Postojna-Bologna, August 24-28. Suppl. Geogr. Fis. Dinam. Quat., III, T. 2 (1997), 167-180, Comitato glaciologico Italiano, Torino.

Curl, R. L., 1986: Fractal dimensions and geometries od caves. Mathematical geology, 18 (8), 765-783.

D'Ambrosi, C., 1960: Sull'origine delle doline carsiche nel quadro genetico del carsismo generale. Bolletino della SASN in Trieste, 51, 205-231, Trieste.

Ford, D.C; R.O. Ewers, 1978: The development of limestone cave systems in the dimensions of lenghth and breadth. Canadian journal of earth science 15, 1783 -1798.

Ford, D. C.; P.W., Williams, 1989: Karst geomorphology and hydrology. Unwin Hyman, 1 - 601, London.

Gams, I., 1966: Factors and dynamics of corrosion of the carbonatic rocks in the Dinaric and Alpine karst of Slovenia (in Slovene, English summary). Geografski vestnik 38, 11 - 68, Ljubljana.

Klimchouk, A., 1995: Karst morphogenesis in the epikarstic zone. Cave and karst science, 21 (2), 45 - 50.

Lowe, D. J., 1992: The origin of limestone caverns: an inception horizon hypothesis. Unpubl. PhD thesis, Manchester Polytechnic, 1 - 512.

Lowe, D. J., J. Gunn, 1997: Carbonate speleogensis: an inception horizon hypothesis. Acta carsologica, 26 (2), 457 - 488, Ljubljana.

Mihevc, A., 1995: The Morphology of shafts on the Trnovski gozd plateau in west Slovenia. Cave and Karst Science, (1994) , 21, 67-69.

Mihevc, A., 1996: The cave Brezstropa jama near Povir (in Slovene, English abstract). Naše jame, 38, 65 - 75, Ljubljana.

Mihevc, A., 1998-a: Roofless cave near Povirje and denuded caves in the vicinity of Divača (in Slovene, English abstract). Geografski obzornik, 45 (2), 12-17, Ljubljana.

Mihevc, A., 1998-b: Dolines, their morphology and origin. Case study: dolines from the Kras, West Slovenia (The Škocjan Karst). Fourth International Conference on Geomorphology, Suppl. Geogr. Fis. Dinam. Quat., III, T. 4 (1998), 69-74, Torino.

Mihevc, A., A. Kranjc, 1998: Classical Karst fieldtrip guide. Fourth International Conference on Geomorphology, Meeting M3, Lipica, august, 24-28, 1997, 1-53, Postojna.

Mihevc, A., T. Slabe, S. Šebela, 1998: Denuded caves - an inherited element in the karst morphology: the case from Kras. Acta carsologica 27 (2), 165 - 174.

Mihevc, A., N. Zupan Hajna 1996: Clastic Sediments from Dolines and Caves Found During the Construction of the Motorway near Divača, on the Classical Karst. Acta carsologica, 25, 169-191, Ljubljana.

[7] *The titles of summaries are given to show English readers the contents of the original texts, which are considered in their entirety in this paper.*

Pezdič, J., F. Šušteršič, M. Mišič, 1998: On the role of clay-carbonate reactions in speleoinception; a contribution to the understanding of the earliest stage of karst channel formation. Acta carsologica 27 (1), 187 - 200, Ljubljana.

Šebela S., A. Mihevc 1995: The problems of construction on karst - The examples from Slovenia. Karst Geohazards, Engineering and Environmental Problems in Karst Terrane, Proceedings of the Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts on Karst / Ed. Barry F. Beck, 475-479, Rotterdam / Brookfield.

Šušteršič, F., 1973: On the problems of collapsed dolinas and allied forms of high Notranjsko (South-central Slovenia). (in Slovene, English summary). Geografski vestnik, 45, 71-86, Ljubljana.

Šušteršič, F., 1982: Some considerations about the spatial organization of the karst terrains. (in Slovene, English summary). Geografski vestnik, 54, 19-28, Ljubljana.

Šušteršič, F., 1987: The small scale surface karst and solution dolines at the north-eastern border of Planinsko polje (in Slovene, English summary). Acta carsologica 16, 51 - 82, Ljubljana.

Šušteršič, F., 1994-a: The Kloka cave and speleo-inception (in Slovene, English summary). Naše jame, 36, 9 - 30, Ljubljana.

Šušteršič, F., 1994-b: Classic dolines of classical site. Acta carsologica 23, 123 - 154, Ljubljana.

Šušteršič, F., 1996: Poljes and caves of Notranjska. Acta carsologica 25, 251 - 289, Ljubljana.

Šušteršič, F., 1997: Cave patterns north of Planinsko polje (Slovenia). Proc. of the 12th International Congress of Speleology, Vol. 1, Physical speleology, Karst geomorphology, La Chaux-de-Fonds. 117-120.

Šušteršič, F., 1998: Rakovska kukava - collapse or tumour doline? Acta carsologica 27/1, 231 - 259, Ljubljana.

White, W. B., 1988: Geomorphology and hydrogeology of karst terrains. Oxford university press, 1 - 464, New York.

Worthington, S.R.H., 1991: Karst hydrogeology of the Canadian Rocky Mountains. Unpubl. PhD thesis, Mc Master University, 1 - 227, Hamilton.

JAMSKI SISTEM IN ZNIŽUJOČE SE POVRŠJE KRASA

Povzetek

Dejstvo, da denudacija, ki neprestano znižuje kraško površje, odpira in briše tudi kraške votline znotraj matične kamnine, se zdi samoumevno. Enako samoumevno velja tudi tihi prevzetek, da so razpoznavni površinski izdanki podzemskih kraških pojavov izjeme, s katerimi si - vsaj s stališča preučevanja speleogeneze - ni kaj pomagati.

Odločilni korak od registriranja posebnosti k sistematičnemu pristopu, je na osnovi znanja pridobljenega na avtocestnih delih na Krasu, storil A. Mihevc (1995, 1996, 1998-a, 1998-b,) s sodelavci (Šebela, Mihevc, 1995; Mihevc, Zupan Hajna, 1996; Cucchi, Mihevc, Ferarese, Sauro, 1997; Mihevc, Kranjc, 1998; Mihevc, Slabe, Šebela, 1998). Ko poroča o prvi resno raziskani denudirani jami pri nas (1996, 66), pravi: "*Čeprav jamski rov brez stropa nekako ni več jama, je prej jarek, vseeno zasluži pozornost. V času, ko se del speleologov usmerja v preučevanje procesov, ki pripeljejo do začetka nastajanja jam, nam rov pokaže na drugi konec speleogeneze, na spremembo jame v površinsko kraško reliefno obliko ali celo popolno izginotje jame. Pomaga nam tudi razložiti sige, ki jih najdemo na površju, najdbe kremenovega proda, peska in ilovic in dojeti zniževanje kraškega površja*." S tem je povedano vse - kar lahko še dodamo, je bolj širjenje kot poglabljanje.

Podpisani sem - v okviru sistematičnega raziskovanja krasa v profilu Borovnica - Kališe (Šušteršič, 1987, 1994) v letih 1994-98 detaljno kartiral drobne kraške oblike v Laškem Ravniku, vzhodno od Planinskega polja. Na osnovi znanja, pridobljenega pri proučevanju jamskega sestava Vranja jama-Najdena jama-jama Kloka (Šušteršič, 1994-a), je postalo jasno, da v Ravniku izdanja doslej neznan, denudiran, popolnoma freatičen jamski sistem (Šušteršič, 1997; Pezdič, Šušteršič, Mišič, 1998).

Posameznosti so povsem primerljive onim na Krasu (Mihevc, Slabe, Šebela, 1998); je pa tamkajšnji sistem (Mihevc, 1998-a) doživel dokončno oblikovanje v epifreatičnih razmerah in je zato jamarskim izkušnjam blizu. Nasprotno obsega denudirani sistem v Ravniku spodnje dele svežnja, ki so v času delovanja povsem zaliti, kasneje pa jih večinoma zaplavijo sedimenti in je naše znanje o njih bistveno bolj deducirano kot izkustveno. Zato je delo potekalo precej drugače kot na Krasu - je pa bilo mogoče spoznati marsikatero obliko, o katerih nekaj sicer vemo, nismo pa doslej mogli prav oceniti njihove vloge znotraj spleta. Ker so skladi in s tem začetni horizonti nagnjeni okrog 20^{o}-30^{o} (proti zahodu), je bogastvo denudiranih oblik precejšnje, laže pa tudi razpoznamo organizacijo jamskega spleta.

Zdi se, da je osnovni nabor denudiranih oblik v Ravniku do danes že poznan. Tekoče in bodoče proučevanje je usmerjeno bolj v spoznavanje velikosti in zgradbe spleta ter dinamiki njegovega zaplavljanja. Na prvi predstavitvi poleti 1997[8] sem želel pokazati, da lahko podzemske kraške pojave, ki jih denudacija "prinese" na kraško površje, opazujemo in preučujemo v dosti večji meri, kot smo domnevali doslej. Na tem mestu povedano nadgrajujem in navajam osnovne tipe izdankov denudiranega freatičnega spleta oz. doslej ugotovljene "površinske" oblike takšnega izvora. O ostalem samo nekaj namigov - raziskovanje v več smereh je v teku.

[8] *Peta Mednarodna krasoslovna šola, Postojna 1997.*

Nabor podzemskih kraških oblik, ki jih lahko razpoznamo na površju, je pester. V primernih okoliščinah lahko zaznamo in preučujemo tudi takšne, ki so sicer človeku nedostopne in bi o njih lahko le sklepali. Ko pa se pokaže slika celotnega spleta freatičnih kanalov, se pokaže dosti večja urejenost, kot smo jo kdajkoli pričakovali. In končno - površinsko kartiranje denudiranih jam[9] je privleklo na dan tudi doslej povsem neznane pojave.

V nadaljevanju podajam osnovne tipe izdankov denudiranih jam v Ravniku. Nadalnje raziskovanje bo shemo verjetno še nekoliko dopolnilo, na obravnavanem ozemlju pa bistvenih sprememb verjetno ni več pričakovati.

Neposredno razpoznavni jamski kanali

Razen vadoznih jaškov, ki so očitno najmlajši, so v Ravniku vse denudirane jamske oblike popolnoma freatične in skoraj do kraja zadelane s sedimenti. Med neposredno razpoznavne jamske kanale štejemo previse in kratke poševne votline, ki jih takoj zadela polnilo. Četudi je vse bolj ali manj prizadelo površinsko preperevanje, zlasti zmrzal, je jasno, da nobeden ni doživel epifreatičnega oblikovanja. Prevladujejo kanali vzdolž lezik, pa tudi freatični skoki niso ravno redki. Struktura 17 - d / 2 (Slika 2) je primer kombinacije obojega. Na daljšo razdaljo odprtih rovov, kakršen je npr. na vhodu Koševelca, na kartiranem ozemlju ni. Kakor se krčijo njihove izmere, število manjših kanalov hitro narašča. Moramo pa se le zavedati, da manjše od približno 0,5 m pri kartiranju zaznamo vse težje. Vsi freatični kanali so nastali ob lezikah; le manjšina kaže določen vpliv razpok. Na pogled je večina usmerjenih v smeri padnice skladov. Kanalov, ki bi na večjo razdaljo tekli vzdolž slemenitve, takorekoč ni. Nekoliko manj številni so freatični skoki. Podobni so žrelom zasutih brezen ali zelo majhnim vrtačam. Razpoznati se jih je dalo šele po drugotnih znakih in lahko bi jih bilo tudi več.

Ob upoštevanju načela ergodičnosti - zakaj ne - lahko na osnovi opazovanja številnih objektov sestavimo logični niz oblik, ki nastanejo pri postopnem zniževanju površja (Sl. 3). Kadar izgine večina jamskih sten, padavinska voda odplavi tudi zadnje ostanke sedimenta in izpostavi doslej zaščiteno jamsko dno. Površje se odtlej znižuje z nižjega mesta kot v okolici in pod nekdanjim jamskim rovom nastane vdolbina, ki jo kaotično zniževanje površja sčasoma zabriše. Neposedno jo težko razpoznamo - šele če najdemo v neposredni bližini začetni horizont ali ostanke sedimenta, je takšna razlaga vsaj dovoljena.

Drobnozrnati jamski sediment

Prej navedene jamske oblike so delno izprane in zato razpoznavne brez težav. Dosti pogosteje se pojavlja ilovnato polnilo, ki je kljub razpadu jamskih sten ostalo na mestu. Dolgo časa je veljalo za površinski sediment predkraške Cerkniščice in šele podrobnejše preučevanje je pokazalo, se prvotno nahaja v denudiranih votlinah.

Daleč prevladuje rjava ilovica, kateri so primešani sorazmerno veliki, delno zaobljeni kosi oolitnega karnijskega boksita in grobi odlomki črnega roženca. Kaže, da je ta sediment v obliki blatnega toka zapolnil spodnje dele delujočega svežnja. Ker so drugi jamski sedimenti v Ravniku mlajši, sem mu dal delovno ime *bazalno polnilo*.

[9] *V mednarodnih krogih se je že uveljavil mimogrede skovani angleški izraz "surfacecaving", primernega slovenskega pa še nimamo. Za denudirane epifreatične jame s poudarjeno vodoravno komponento je poimenovanje "brezstropa jama", ki so ga vpeljali raziskovalci IZRK ZRC SAZU, prav posrečeno - različni izdanki poševnih kanalov pa na krst še čakajo.*

Na dveh krajih se v soramerno velikih rovih (okrog 10 m) pojavlja laminiran, nekoliko sprijet mulj, ki spominja na varve. Kaže, da je mlajši kot *bazalno polnilo*.

Na enem samem mestu je v žepu (morda votlini) delno cementiran karbonatni pesek, v katerem so kremenovi kristali.

Ko se kamnina, ki obdaja zasuto jamo, popolnoma razkroji, netopno polnilo vztraja na novonastalem površju pod nekdanjo jamo. Dokler ga nadalnja denudacija dokončno ne razprši, se do neke mere še da ugotoviti potek izginulega rova. Takšne pojave sem imenoval *fantomske jame*.

Ob nadalnjem zniževanju površja se boksitni prodniki in roženec lahko spet zberejo v kakem žepu. Takšna nahajlišča imenujem sekundarna.

Debelozrnati sedimenti

Dosti redkejši od prej naštetih so izdanki konglomerata. Prodniki so kaj različni - od debelozrnatega peska da nekajcentimeterskih oblic (Sl. 5). Kot izvorna kamnina daleč prevladuje norijskoretijski dolomit, navzoči pa so še manj zaobljeni kosi jurskega apnenca krajevnega izvora. Najdemo tudi boksit in črni roženec, za katera doslej še ni bilo mogoče ugotoviti, ali sta prispela skupaj s prodom, ali pa sta se primešala šele na kraju samem. Ponekod so prisotni tudi popolnoma nezaobljeni kosi, ki so se odlomili s sten kanala v neposredni bližini.

Konglomerat kaže značine fluvialne teksture kot “graded bedding”, pasovito sedimentacijo itd. Vezivo je glinasto, njegov delež pa se spreminja od komaj zaznavnega do prek 70%. V zadnjem primeru posamezni večji prodniki “plavajo” v osnovi. Večina dolomitnih prodnikov je izvotljenih, kar odraža vadozno diagenezo. Torej je konglomerat (prod) prišel v sistem sorazmerno pozno, ko so že vladale vadozne razmere. Dodatno to potrjuje siga, ki se pojavlja pod, med in nad konglomeratom.

Konglomerat je praviloma enako odporen kot okoliška kamnina in v njem celo nastajajo škraplje. Ponekod najdemo posamezne bloke, ki “plavajo” v *bazalnem polnilu*. Zato smo prvotno sklepali, da je *bazalno polnilo* netopni ostanek preperelega konglomerata. Danes pa se kaže, da je bilo odloženo dosti pred prodom/konglomeratom, ki se je usedel tja, kjer je bilo delno izprano. “Plavajoči” bloki so posledica recentnega, popolnoma lokalnega razkroja konglomerata.

Siga v denudiranih jamah

Siga se večinoma javlja skupaj s konglomeratom, kaže pa, da sta se odlagala izmenično. Pojavlja se v obliki masivnih sigovih skorij in polovičnih stenskih stalaktitov (Sl. 6), ni se pa še pokazal samostojno stoječi stalagmit. Gmota je popolnoma prekristaljena, tako da je prvotna struktura večinoma zabrisana. Laže je opazna tam, kjer je sigi primešana ilovica. Če pa je siga popolnoma steklasta, so veliki kristali orientirani popolnoma poljubno. Marsikje je konglomerat pod sigovo prevleko korodiran/erodiran.

Večino sige najdemo na stenah nekdanjih jamskih kanalov, ali pa tam, kje je to zelo verjetno. Javlja se tudi v popolnoma zasiganih razpokah (Sl. 7), vendar praviloma ne dlje kot 20 m od najbližjega večjega kanala. Takšno sigo sem imenoval *avreolno sigo*. Najpreprostejša razlaga se zdi, da temelji na koncentraciji CO_2 v prenikli vodi. Ko zapusti pas koreninja, je glede na zunanjost z njim prezasičena in se zato zasiti tudi s $CaCO_3$. Dokler potuje po ozkih kanalih, se ustrezna atmosfera vzpostavi tudi tam in ravnotežje se ohranja. Šele ko pride v bližino večje, prezračene votline, prične oddajati CO_2, s tem pa se sprosti tudi $CaCO_3$ oz. odloži siga. Torej je *avreolna siga* eden indikatorjev bližine večje kraške votline.

Sige v denudiranih jamah so po vsej podobi starejše od dometa U-Th metode in jih zato nismo poskusili datirati.

Male udornice

Da se tudi v Ravniku pojavljata dva tipa udornic - "male", ki nekako ustrezajo preprosti predpostavki o zrušenju jamskega stropa in "velike", ki so doživele naknadno večanje, sem verjetno prvi zabeležil podpisani (Šušteršič, 1973, 75). Isto je za Divaški kras ugotovil A. Mihevc (1998-b, 72), ki je "male" logično povezal z denudacijo površja. Na obravnavanem ozemlju je doslej nedvomno identificirana samo ena, verjetno genetsko povezana s freatičnim skokom.

Splošni oris jamskega spleta v Laškem Ravniku

Odlomki jamskega spleta, odkriti v Laškem Ravniku, so očitno freatični. Zato se ponuja možnost, ugotoviti prostorski razmah spleta kanalov znotraj svežnja. Podrobno kartiranje, ki je zajelo takorekoč vsako podrobnost, je doslej pokrilo samo okrog poldrugega km^2 in znotraj tega obsega se še nikjer ni nakazala bližina roba svežnja. Le pregledano je bilo nekajkrat večje ozemlje, kjer se kaže, da območje izdanjanja *bazalnega polnila* omejujejo večje tektonske strukture. Pri tem je najznačilnejša ločnica Idrijski prelom, ki poteka nekaj km zahodnje od kartiranega ozemlja. Konglomeratno območje, se zdi, da omejuje Idrijskemu vzporeden prelom, na katerega zdrobljeno cono smo večkrat naleteli na sevrovzhodnem obrobju Ravnika.

Zaporedje procesov je bilo že nakazano; ponovimo le osnovni vzorec. Najstarejši je splet freatičnih kanalov, ki bi mogel biti enake starosti, kot z Idrijskim prelomom razmaknjeni jamski sistemi (Šušteršič, 1996). Še v popolnoma freatičnih razmerah je spodnji del svežnja (zgornjega je kajpak odstranila denudacija) v višinskem razponu najmanj 100m zaplavilo *bazalno polnilo*. Dosti pozneje je bil del rovov izpran, vanje pa sta se, v višinskem razponu njamanj 20m, v vadoznih razmerah odlagala siga in prod/konglomerat. O treh "izjemnih" sedimentih še ne moremo razpravljati.

Izvor sedimentov je bolj jasen. V *bazalnem polnilu* bi vsaj boksit lahko izviral iz gornjega dela porečja Cerkniščice. Ker pa imamo opraviti z velikim časovnim razponom, bi pri stopnji denudacije 65m Ma^{-1} (Gams, 1966) lahko bilo izvorno področje do danes že popolnoma izbrisano. Konglomerat z izjemo lokalnih odlomkov popolnoma ustreza današnjemu tovoru Cerkniščice in verjetno izvira iz njenega porečja.

Vse večje število vse manjših neposredno zaznavnih kanalov nakazuje, da bi lahko veljal R. Curlov (1986) fraktalni model (Mengerjeva spužva) organizacije jamskega spleta. Žal so bile njihove izmere doslej le ocenjene, kar pri tako majhnem vzorcu še ne dovoli stabilne statistike. Kaže, da se večji kanali (nad 5 m) pojavljajo v parih ali celo trojkah. Podobno se da videti tudi v stenah apneniških Alp, razlage pa še ni.

Slika 1 jasno kaže, da se večina freatičnih kanalov pojavlja ob stikih apnenca z dolomitom. To se sklada D.J. Lowejevo hipotezo (1992) o začetnih horizontih, posebej učinkom "trans-bedding contrast"-a. Računalniška simulacija je potrdila hipotezo, da bi začetni kanali lahko nastajali z rekalcitizacijo dolomita (Pezdič, Šušteršič, Mišič, 1998) - zdi pa se, da to ni edini možni proces. Precej kratkih kanalov najdemo v bližini začetnih horizontov in se tja tudi hitro vračajo, kar ima za posledico veliko število freatičnih skokov. Isto sem opazil tudi v širšem sistemu Najdene jame (Šušteršič, 1994-a). Verjetno to pomeni, da so začetni horizonti absolutno atraktivni samo v času začetja. Pozneje se tokovi krajevno lahko odklanjajo, a brž spet vračajo.

Zahvala

Zahvaliti se želim svojim študentom, ki so zagnano iskali še neznanih izdankov ter prijateljema Andreju Mihevcu in Davidu J. Loweju, ki sta vsak po svoje prispevala k razumevanju tega, kar je bilo že enkrat najdeno.