| ACTA CARSOLOGICA | 33/1 | 13 | 205-217 | LJUBLJANA 2004 |
| --- | --- | --- | --- | --- |

COBISS:1.01

# KARSTIFICATION OF THE AQUIFER DISCOVERED DURING THE CONSTRUCTION OF THE EXPRESSWAY BETWEEN KLANEC AND ČRNI KAL, CLASSICAL KARST

# ZAKRASELOST VODONOSNIKA, RAZKRITA PRI GRADNJI AVTOCESTE MED KLANCEM IN ČRNIM KALOM, KLASIČNI KRAS

MARTIN KNEZ[1] & TADEJ SLABE[1] & STANKA ŠEBELA[1]

[1] Karst Research Institute, ZRC SAZU, Titov trg 2, SI-6230 POSTOJNA, SLOVENIA; knez@zrc-sazu.si, slabe@zrc-sazu.si, sebela@zrc-sazu.si

Prejeto / received: 14 .2. 2004

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

**Martin Knez & Tadej Slabe & Stanka Šebela: Karstification of the aquifer discovered during the construction of the expressway between Klanec and Črni Kal, Classical Karst**

Sixty-seven caves were opened during the earth removal and the excavation of the tunnel on the 6.5 km route section of the expressway between Klanec and Črni Kal. By their number, old caves predominated. Two - thirds of these caves were filled with deposits. The caves investigated contributed to our knowledge of the development of this part of the karst. The more than 450 m - long cave system of caves which we are trying to preserve was opened in the tunnel at Kastelec near the Škrklovica cave. Below the road, the passages of this system are connected with concrete pipes, leading from the roadside.
**Key words:** karstology, expressway construction, karst caves, Kras (Classical Karst), Slovenia.

**Izvleček** UDK: 551.44:625.7/.8(497.4)

**Martin Knez & Tadej Slabe & Stanka Šebela: Zakraselost vodonosnika, razkrita pri gradnji avtoceste med Klancem in Črnim Kalom, klasični Kras**

Med Klancem in Črnim Kalom se je na 6,5 km trase avtoceste med zemeljskimi deli, kopanju usekov in predora odprlo 67 jam. Številčno so prevladovale stare jame, torej tiste, skozi katere se je nekoč pretakala voda. Dve tretjini teh jam je bilo zapolnjenih z naplavino. Raziskane jame so nam dopolnile znanje o razvoju tega dela krasa. Prek 500 m dolg jamski splet, katerega smo se trudili ohraniti v celoti, se odprl v predoru Kastelec v bližini Brezna na Škrklovici. Rovi tega spleta so pod cesto povezani z betonskimi cevmi, do katerih vodi jašek z roba cestišča.
**Ključne besede:** krasoslovje, gradnja avtocest, kraške jame, Kras, Slovenija.

## INTRODUCTION

Karstologists are directly involved in the planning and construction of Slovenian expressways (Slabe 1996,1997a; Kogovšek et al. 1997; Šebela et al. 1999; Knez & Slabe 2000, 2001) built on the Classical Karst (Kranjc et al. 1997, 1999). In last ten years 320 caves were opened on a 50 km stretch of new expressways. Considerable activity took place at the edge of the karst and in its hinterland during the construction of the tunnel and major excavations, which in many locations uncovered the epikarst and parts of the vadose zones, both of which are criss-crossed with old caves, developed in former phreatic and epiphreatic conditions. Besides the paleokarst, these caves are the oldest indications of the development of this part of the karst. The caves discovered during construction helped us obtain new knowledge about the cavernosity of the karst and about its development.

## THE KARST SURFACE AND KARSTIFICATION

The route runs on alveolinid-nummulitid limestone and, to a minor degree, on flysch rock formations. It crosses several overthrust deformations between carbonate rock and Eocene flysch.

After the deposit of Eocene flysch, during the Pyrenean phase, the rock folds ran in the NW-SE

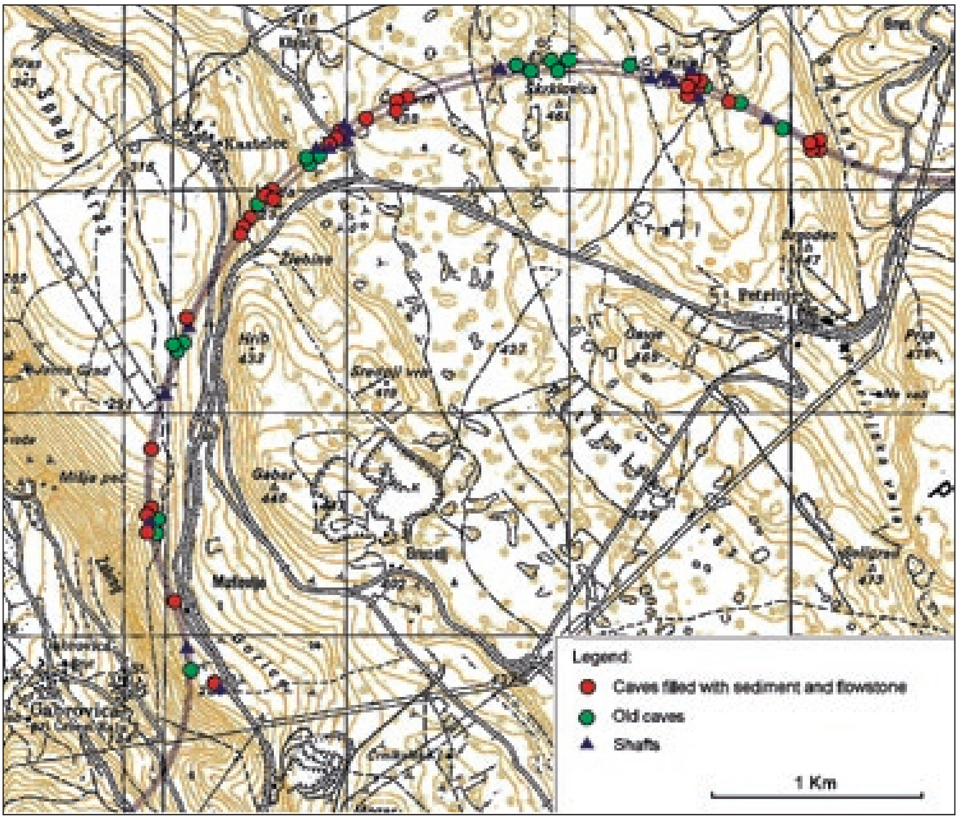


*Fig. 1: Part of expressway with newly discovered caves.*

direction. Later the folds were deformed by overthrust, normal and longitudinal faults. The area between Petrinje and Črni Kal is categorised as a napped structure of the Čičarija overthrust unit (Pleničar et al. 1969). The expressway route crosses the folds, overthrusts and fault deformations (mainly in the NW-SE and NE-SW directions). The up to 100 m-wide fissured zones in the general N-S direction for the most part represent opened fissures along which shafts and systems of karren have developed. Such fissures are very suitable for karstification.

**Alveolinid-nummulitid limestone**

Alveolinid-nummulitid limestone, which represents the end phase of carbonate sedimentation in south-western Slovenia, lies concordantly on miliolid limestone. Fauna of the Alveolinidae and Nummulitidae families are predominant in this limestone, and are often so frequent that the rock is named after them.

The thickness of the layers changes laterally. At some points the thickness cannot be determined. Mainly the upper part of the alveolinid-nummulitid limestone is more compact and homogenous; also bedding is less distinctive in this area.

The biomicritic and biosparitic limestone, mostly of the packstone type, is usually light brown, light grey or yellowish white coloured. It contains numerous fossils of the alveolinids, nummulitids and discocyclinids. Locally, we can also find brachiopods, echinoids, corals, lithothamnians, various lamellibranchs and others.

*Fig. 2: Unroofed part of the cave.*

Alveolinid-nummulitid limestone was in most cases continuously deposited on the miliolid limestone. With regard to the type of the limestone, it was concluded that the sedimentation area was an open and shallow shelf; elsewhere the sedimentation conditions were calmer. There, the sedimentation took place in the restricted areas of the open shelf or in small lagoons (Jurkovšek et al. 1996).

Nummulites are the most frequent fossil remains in the alveolinid-nummulitid limestone, with a thickness varying laterally between a few and up to 300 m. Generally the nummulites, operculines and assilines are mixed and almost always all three genera are present. In some

*Fig. 3: Part of the cave system filled with sediment and flowstone.*

*Fig. 4: Cave-wall seen during the tunnel construction.*

cases the nummulites predominate; thus some limestones are called nummulitid, while others are called operculinid limestone. Assilines are usually less present in the samples.

**Flysch**

On the border with flysch layers, we find the so-called transitional layers, between carbonate and non-carbonate rock, which mainly includes marl and marl limestone, and often contains pelagian foraminifers. A longer or shorter hiatus occurs laterally between the two formations.

The flysch, represented by sequences of marl, sandy siltstone, and coarse-grained carbonate sandstone with intermittent thicker or thinner insertions of breccia and conglomerates, was overthrust onto the alveolinid-nummulitid limestone in a napped formation. The joint is an important area of the characteristic speleogenetic development. It is known that the contact of limestone with an impermeable rock is not only a water barrier, but also an area where water accumulates and forms larger water channels through which it washes material into the underground.

**Karstification of alveolinid-nummulitid limestone**

Past research results have shown that alveolinid-nummulitid limestone, compared to stratigraphically closer neighbouring limestone, is more resistant to erosion. In most cases, mainly the surface and the areas close beneath the surface were karstified, while deeper down, karstification occurs only exceptionally. Surface karstification is strongly expressed mainly on sloped terrain, where the formation of diluvial sediments occurs. Despite this, alveolinid-nummulitid limestone can be topographically distinguished from the lower-lying miliolid limestone by its more intense surface karstification and by the numerous karren that shape the rock surface.

Alveolinid-nummulitid limestone decays in plates, breaks up into rubble or forms an anomalous structure. The soil that covers the bedrock is often only a few decimetres thick.

A detailed study of the influence of the rock type on the number of cave entrances was conducted in the direct vicinity of the surveyed area. The conclusion was (Knez 1995; 1996) that the Liburnian Formation, which also include alveolinid-nummulitid limestone, are considerably less deeply karstified than the Cretaceous beds. The Liburnian Formation reaches 3/4 of the average 1.01 cave/km$^2$, which is characteristic for the examined area, and the alveolinid-nummulitid limestone reaches barely 0.43 cave/km$^2$. The values for the Senonian (2.42 cave/km$^2$) and for the Turonian (2.18 cave/km$^2$) are considerably higher.

In order to assess the cavernosity of the karst between Petrinje and Črni Kal, we measured the karst caves in the Črnotiče quarry, which were uncovered by the quarry excavations, with a theodolite. These are shafts, horizontal caves and vertical fissures, mostly filled with cave sediment and flowstone. The diameter of the passages is up to 15 m and the length is up to 220 m. Some of the caves were located immediately below the surface, while others opened several meters lower. Some were filled with sand and alluvial clay; in some cases rubble and sometimes flowstone was deposited on the sand and clay. We measured and mapped some of the karst caves which were not totally filled with sediment. Later these caves were destroyed and removed by quarry work.

We used the geodetic measurements of the quarry caves for calculating the cavernosity. In a chosen mass of rock (300 x 400 x 19 m) we calculated the volume of the cave passages for 13 geodetically measured caves, and it amounted to 89,074 m$^3$ or 3.9 %.

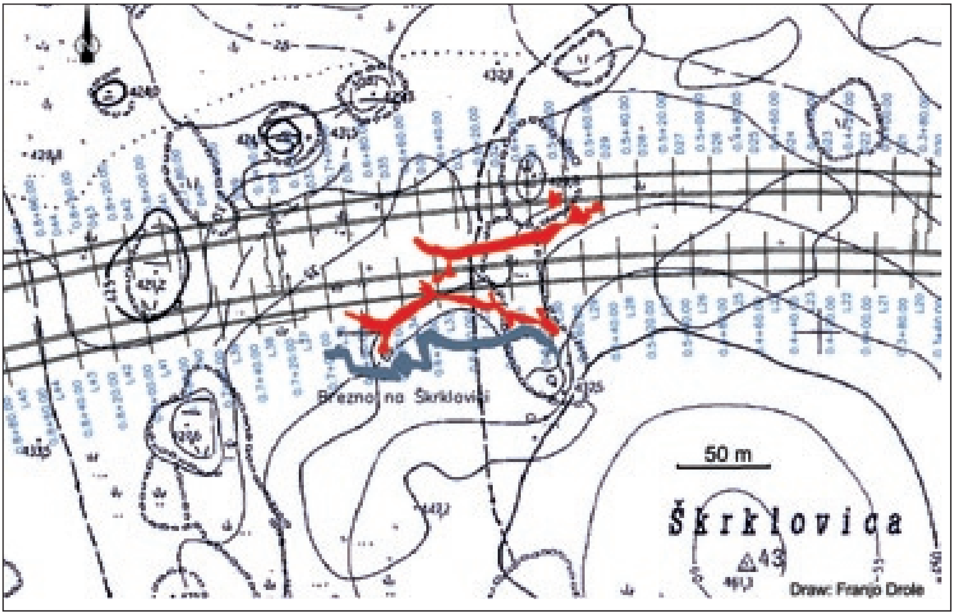


*Fig. 5: The largest cave system.*

*Fig. 6: Cave in the tunnel (Photo: Feruccio Hrvatin).*

## EPIKARST

Underground karren with a characteristic subcutaneous rock relief (Slabe 1998) had formed under the thin layer of soil. The distinctively crumbled rock had already decayed into individual, mainly small, particles, which were reshaped under the ground and thus obtained a more rounded form. The structure of the rock shows on their surfaces, which were exposed to uniform decaying. Paleogenic fossils often stick out of the surface. Underground grooves and scallops formed in the area of contact between the limestone and flysch. The lower faces of the basal conglomerates in the flysch show characteristic above sediment anastomoses.

In Kozina, a paleokarstic surface with remains of dinosaurs and other animals was uncovered just beneath the present surface (Debeljak et al. 1999).

## DISCOVERED CAVES

Sixty-seven caves were opened during the earthremoval and excavations of the roadway and the tunnel on the 6.5 km expressway route (Figs. 1, 7). By their number, old caves were predominant (49); two thirds of these were filled with fine-grained alluvium and at some spots with sharp-edged rubble.

Part of the old caves opened as roofless caves (Knez & Šebela 1994; Šebela & Mihevc 1995; Mihevc 1996; Mihevc & Zupan Hajna 1996; Slabe 1996, 1997b, 1998; Mihevc et al. 1998; Knez & Slabe 1999, 2002). Other caves opened at the perimeter of the road cuts and during the excavation of the tunnel. The passages reached up to 8 m in diameter.

A larger system of caves opened on the eastern side of the entrance to the tunnel. A part of the system was already without a ceiling – one part consisted of hollow passages, while the other was filled with deposits and flowstone (Figs. 2, 3, 4). The edges of the passages were characteristically reshaped at the contact of the sediment (Slabe 1995). From the largest passage, we collected 18 samples of deposits for paleo-magnetic examination; the examinations have not yet been completed. Similar to other nearby cave deposits, here we also found flysch deposits, characteristic for the regional position and the development of this part of the karst (Bosak et al. 2000). The outermost upper part of the profile consists of a pebble layer up to 3 m thick. Lower down (2 m) a more sandy layer occurs, while the lowest layer is argillaceous. The sediment is yellowish brown (10YR 5/6) to light olive grey (5Y 6/2) colour. At a distance of 4.5-5 m from the bottom of the profile lies a 1-2 dm-thick connective layer of clay that is of a darker shade (brownish yellow 10YR 6/8) than other sediment in the profile. The altitude of the lower samples is 395 m above sea level. Individual, roofless, parts of the cave resembled dolinas by shape and were clearly visible on the surface even before work began.

The largest cave system (over 450 m long) opened in the tunnel (Figs. 5, 7i) near the already known cave named Škrklovica, and mainly showed traces (large scallops) of slow water flow in a water-filled cave. Three large passages were opened in the tunnel (Fig. 6), but were not interconnected. Apparently this was all a single cave system. The shape of the sloped passages, which measured 8 m in diameter, indicated that the main part of the cave was shaped by water flow and some shafts by percolating water. The large scallops indicate a slow-flowing water current, which mostly contributed to the current shape of the cave, while the ceiling cups indicate that water once completely filled the cave. The ceiling cups are of various shapes, narrow and extremely high (up

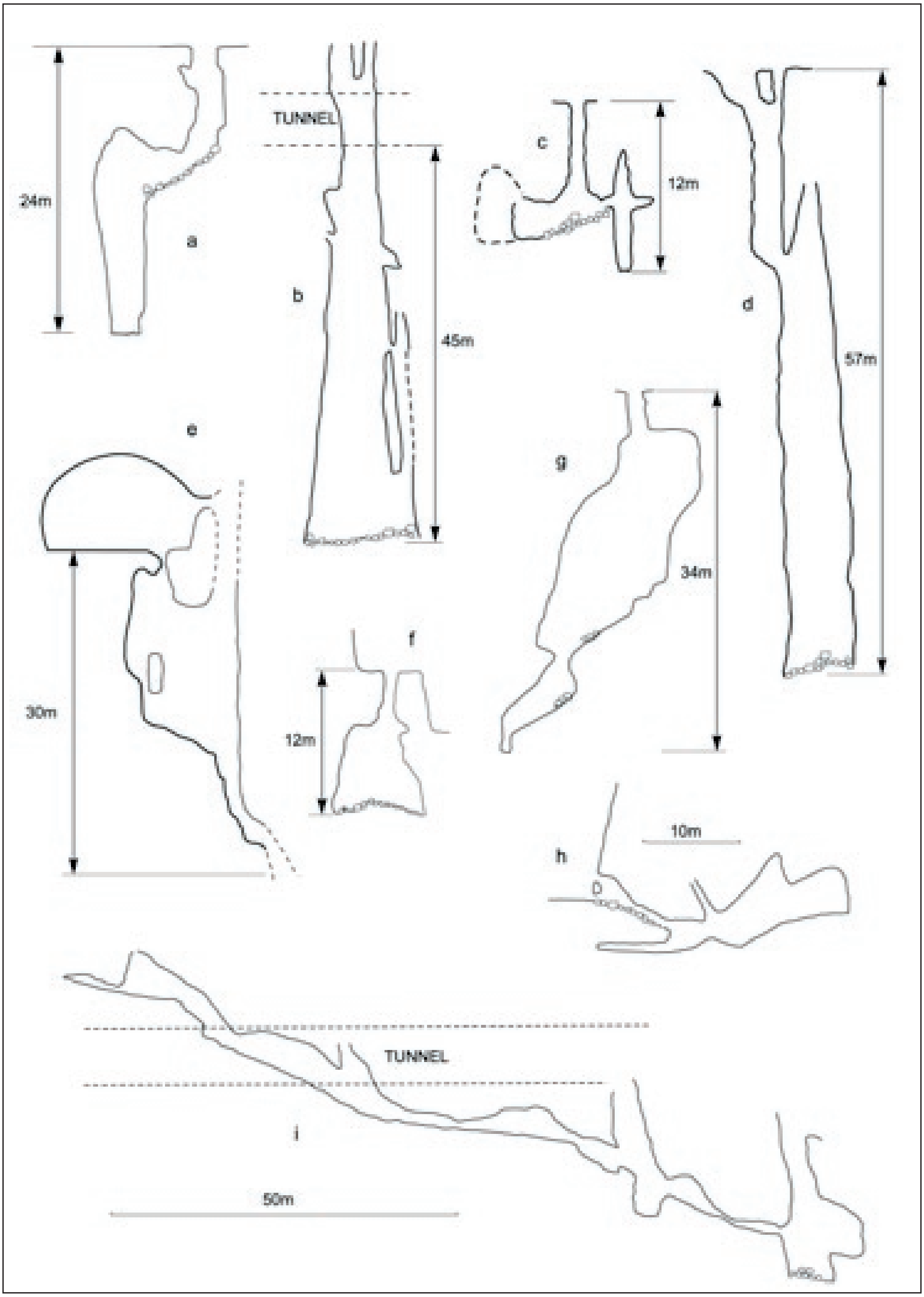


*Fig. 7: Cross-sections of newly discovered caves.*

to several metres) at the cracks; they have relatively level tops and are often connected into smaller or larger ceiling cupolas. The passages were filled with fine-grained alluvium, which the water later had mostly washed out.

On the surface of the entrance shaft (15 m) to the Škrklovica, the layers lie at a 30-40° angle in an E to NE direction. At a vertical distance of 80 m, the direction of the layers slightly changes.

An old cave was opened during excavation for the road, immediately near the steep karst edge, with a system of minor passages, round in the cross-section and with a ceiling criss-crossed by cups and cupolas – formations that were created below the ground water table. At some locations there is a small channel on the bottom of the passage, created by the flow of small quantities of water on the rock floor – a trace of a minor reshaping of the cave (Fig. 7h).

Many of the caves were shaped as fissures formed in vertical cracks, either hollow or filled with deposits. Their width often did not exceed one to two metres, seldom up to three, but they could be up to several tens of metres deep. Those filled with fine-grained deposits had supra-alluvial scallops along their rim (Fig. 7e).

In the area of the above-described cave system, in front of the tunnel, there was a shaft measuring 4 m in diameter. It was filled with fine-grained alluvium. Its walls were shaped with traces of water percolation and only occasionally reshaped under the sediment.

The caves were formed along the contact zone of limestone and flysch. Where the limestone was above the flysch, the caves were mostly formed in the flysch. The diameter of these caves was 2 m. They were entirely filled with flowstone and fine-grained deposits.

Eighteen shafts were opened, the deepest reaching 85 m deep. There were deposits of old flowstone in some of them, which the water dripping along the walls slowly disintegrated (Figs. 7a, b, d, f).

## CAVES AS A SIGN OF THE DEVELOPMENT OF AN AQUIFER

Caves which were opened during the construction work uncovered important periods in the development of this part of the karst. The epikarst and the upper part of the now vadose zone are criss-crossed by various traces of karst development through several periods. In the oldest caves we find traces of the cavernosity of the aquifer, when the preserved part of the karst was entirely shaped below the water table, which is today 230 m below the earth's surface. Due to the lowering of the karst surface, some of the caves are now unroofed (Knez & Slabe 2002). The shapes of the other caves show their formation in a phreatic zone. Most of them were filled with fine-grained deposits, which was in some cases later washed out. The alluvial filling of the caves is connected to the raising of the ground water level following the Messinian crisis (Bosak et al. 2000). The yet uncompleted paleo-magnetic examinations will show us the timeline of the cave at Kozina. It appears that the shaft, which was filled with fine-grained deposits, reveals a distinct period of formation of the upper part of the aquifer in vadose conditions, before the floodwaters reached it.

This was followed by a relatively swift transition of the formation of this part of the karst into vadose conditions. Apart from the alluvial traces consisting mainly of deposits and rare traces of faster-flowing water, there are no distinct signs of formation in epiphreatic or vadose conditions. This part of the karst is today being shaped by dispersed water percolation from the karstic surface. The caves with water develop only at the contact area of flysch and limestone, where streams flow into them. The development of this part of the karst is thus closely connected with the swift drop of the ground water level.

A part of the old caves is filled with sharp-edged rubble which was formed by the disintegration of the rock during the cold Pleistocene periods.

At several locations we noticed that the water, which percolates from the surface and drips along the walls of the shafts, either independent or those that shape older caves, dissolves the flowstone which used to cover these walls. Will further research reveal that this is the result of the widening of cracks or of changes in the karst surface, or maybe even of the impact of human activities - deforestation?

## CONSTRUCTION AND CAVE PRESERVATION

All the caves discovered during expressway construction were measured, mapped and researched. We tried to preserve as many as possible, in cooperation with the road builders. At the edges of the construction, they are hidden behind the rock embankments and behind the concrete perimeter of the tunnel. Those below the road with narrower openings, which were not too crumbled along their rims by the mining, are covered with concrete slabs. We tried to fully preserve the largest cave system in the tunnel. The passages of this system are connected by concrete pipes below the road, accessible through a shaft located in the tunnel, at the edge of the road.

## CONCLUSION

Sixty-seven caves were opened during the construction of the 6.5 km expressway route. Caves through which water once flowed (49) predominate. In the tunnel on the north-western part of Škrklovica hill (461 m) we discovered a major cave system genetically connected to the already known Škrklovica shaft. A large part of the caves was filled with fine-grained deposits. Alveolinid-nummulitid limestone, on which most of the expressway route runs, is relatively resistant to karstification and in most cases only its surface and the parts close to the surface are distinctly karstified. The signs of karstification through various periods can be followed in the epikarst in the upper part of the now vadose zone. The oldest caves signify the cavernosity of the aquifer, when the part of the karst, which is still preserved today, was entirely shaped in the phreatic zone. In some of the caves, consisting of a system of minor passages with round cross-sections, the ceiling is shaped with ceiling cups and cupolas, shapes that were formed when the caves were being formed below the ground water table. This was followed by a relatively swift lowering of the ground water level by reshaping of the older signs of development in vadose conditions.

## REFERENCES

Bosak, P., M. Knez, D. Otrubova, P. Pruner, T. Slabe, D. Vendohova, 2000: Paleomagnetic Research of Fossil Cave in the Highway Construction at Kozina (Slovenia).- Acta carsologica, 29/2, 15-33, Ljubljana

Debeljak, I.& A. Košir & B. Otoničar, 1999: A preliminary note on dinosaurs and non-dinosaurian reptiles from the Upper Cretaceous carbonate platform succession at Kozina (SW Slovenia).-

Razpr. - Slov. akad. znan. umet., 40, 3-25, Ljubljana
Jurkovšek, B. & M. Toman & B. Ogorelec & Lj. Šribar & K. Drobne & M. Poljak & Lu. Šribar, 1996: Formacijska geološka karta južnega dela Tržaško-Komenske planote. Kredne in paleogenske karbonatne kamnine 1 : 50 000.- IGGG Ljubljana, 143 p., Ljubljana
Knez, M. & S. Šebela, 1994: Novo odkriti kraški pojavi na trasi avtomobilske ceste pri Divači.- Naše jame, 36, 102, Ljubljana
Knez, M., 1995: Vreme beds and the genesis of the karst caves in them in wider surroundings of Škocjanske jame (Škocjanske Jame Caves, Slovenia).- Acta carsologica, 24, 291-301, Ljubljana
Knez, M., 1996: Vpliv lezik na razvoj kraških jam. (Primer Velike doline, Škocjanske jame).- Znanstvenoraziskovalni center SAZU, 14, 186 str., Ljubljana
Knez, M. & T. Slabe, 1999: Origin and development of an old alpine cave (Zadlaška jama, Julian Alps).- Acta Carsologica, 28/1, 127-137, Ljubljana
Knez, M. & T. Slabe, 2000: Jame brez stropa so pomembna oblika na kraškem površju: s krasoslovnega nadzora gradnje avtocest na krasu. V: GOSTINČAR, Andreja (ur.). 5. slovenski kongres o cestah in prometu. Zbornik povzetkov referatov. Ljubljana: Družba za raziskave v cestni in prometni stroki Slovenije, 2000, str. 29
Knez, M. & Slabe, T., 2001: Karstology and expressway construction. Proceedings 14th IRF Road World Congress, Paris
Knez, M. & T. Slabe, 2002: Unroofed caves are an important feature of karst surfaces: examples from the classical karst.- Z. Geomorphol., 46, 2, 181-191, Berlin-Stuttgart
Kogovšek, J. & T. Slabe & S. Šebela, 1997: Motorways in Karst (Slovenia).- Proceedings & a Fieldtrip excursion guide, 48th highway geology symposium, 49–55
Kranjc, A. (ed.), 1997: Slovene Classical Karst.- ZRC SAZU, 254 p., Ljubljana
Kranjc, A. (ed.), 1999: Kras. Pokrajina-življenje-ljudje- ZRC SAZU, 321 p., Ljubljana
Mihevc, A., 1996: The cave Brezstropa jama near Povir.- Naše jame, 38, 65-75, Ljubljana
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
Mihevc, A. & T. Slabe & S. Šebela, 1998: Denuded caves.- Acta carsologica 27/1, 165–174, Ljubljana
Pleničar, M. & A. Polšak & D. Šikić, 1969: Osnovna geološka karta SFRJ 1:100.000, list Trst.- Zvezni geološki zavod Beograd, Beograd
Slabe, T., 1995: Cave Rocky Relief and its Speleogenetical Significance: Zbirka ZRC, 10, 128 p., Ljubljana
Slabe, T., 1996: Karst features in the motorway section between Čebulovica and Dane.- Acta carsologica 13, 221–240, Ljubljana.
Slabe, T., 1997a: Karst features discovered during motorway construction in Slovenia.- Environmental Geology 32/3, 186–190, Springer-Verlag
Slabe, T., 1997b: The caves in the motorway Dane-Fernetiči.- Acta carsologica 26/2, 361–372, Ljubljana
Slabe, T., 1998: Karst features discovered during motorway construction between Divača and Kozina.- Acta carsologica, 27/2, 105-113, Ljubljana

Šebela, S. & A. Mihevc, 1995: The problems of construction on karst - the examples from Slovenia.- In: Beck B.F., Pearson F.M. (eds) Karst geohazards, engineering and environmental problems in karst terrain. Proceedings of the Fifth Multidisciplinary Conference on Dolines and Engineering and Environmental Impacts on Karst. A.A. Balkema, Rotterdam, The Netherlands, p. 475–479

Šebela, S. & A. Mihevc & T. Slabe, 1999: The vulnerability map of karst along highways in Slovenia.- In: Beck B.F., A.J. Pettit, J.G. Herring (eds). Hydrogeology and enineering geology of dolines and karst -1999. Proceedings of the Seventh Multidisciplinary Conference on Dolines and the Engineering and Environmental Impacts on Karst. A.A. Balkema, Rotterdam, The Netherlands, p. 419–422