

Speleogenesis and Flowstone Deposition in Križna jama

by

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Zusammenfassung

Die Speleogenese der Križna jama ist einerseits charakterisiert durch eine Serie von allochthonen und autochthonen Materialablagerungen, und andererseits durch mechanische und chemische Erosion dieser Sedimente. Aufgrund der Morphologie der Passagen und anhand von Typ und Ort der Sedimentation können sechs speleogenetische Phasen unterschieden werden; fünf davon sind Ablagerungsereignisse, eine ist eine Erosionsphase. In der Vorbereitungsphase wurden die Hauptäste der Höhle angelegt und in der ersten Phase wurden diese mit allochthonen Geröllen und Sanden verfüllt. In der zweiten Phase wurden diese Sedimente durch Calcit aus Sickerwässern zementiert. Danach wurde die vorige Sedimentationssequenz mit feinkörnigen Sedimenten überlagert. In der vierten Phase waren sowohl in der Križna jama als auch in der Križna jama 2 kein fließendes Wasser vorhanden, was die Überwinterung der Höhlenbären ermöglichte. Die fünfte Phase ist eine Phase starker mechanischer und chemischer Erosion der zuvor in der Hauptwasserpassage abgelagerten Sedimente, wodurch es zu einer Absenkung des Begehungshorizontes um ca. einen Meter gekommen ist. Die letzte (holozäne) Phase ist durch die Ablagerung von Sinter gekennzeichnet, der v.a. in der Form von Sinterterrassen auftritt hinter denen sich schließlich kleine Seen gebildet haben.

Schlüsselwörter: Križna jama, Speleogenese, Sinterablagerung, Slowenien

Summary

The speleogenesis of Križna jama is characterized on the one hand by series of allochthonous and autochthonous material depositions and, on the other hand, by mechani-

cal and chemical erosion of these sediments. On the basis of passage morphology and the type and location of sedimentation, six speleogenetic phases (five depositional and one erosional) can be highlighted. During pre-phase the main trunk passages were formed and during first phase they were filled by mainly allochthonous pebbles and sandy material. During the second phase this material was cemented together by calcite from percolation water. Subsequently, the previous sedimentation sequence was covered by fine-grained sediments. During the fourth phase Križna jama (and also Križna jama 2) was characterized by an absence of water flow, making it suitable for cave bear hibernation. The fifth phase is characterized by strong mechanical and chemical erosion of previously deposited sediments in the main water passage. This phase also saw entrenchment of passages by more than one meter. The last (Holocene) phase is characterized by flowstone deposition in the form of rimstone dams behind which underground lakes formed.

Keywords: Križna jama, speleogenesis, flowstone deposition, Slovenia

Izvleček

Razvoj Križne jame karakterizira serija zapolnitev z alohtonim materialom in sigo ter izpraznenje jamskih rogov v obliki mehanske in kemične erozije. Na podlagi morfologije rogov, tipa in lokacije sedimentov lahko postavimo 6 speleogenetskih faz (5 sedimentacijskih in 1 erozijska). V predfazi je prišlo do oblikovanja glavnih rogov, ki so bili v 1. fazi deloma zapolnjeni s pretežno alohtonimi prodatimi in peščenimi nanosi. V 2. fazi se je ta prod deloma cementiral s sigo iz prenikle vode. Tretja faza je obdobje odlaganja finozrnatih sedimentov. V četrti fazi je vodni tok skozi Križno jamo (in Križno jamo 2) povsem presahnil, v jamo pa je v tem obdobju predvidoma zahajal jamski medved. Peta faza je povezana z močno mehansko in kemično erozijo v glavnih vodnih rovih, ki je odstranila velik del poprej odloženih sedimentov ter poglobila vodni kanal za več kot 1 meter. Zadnja

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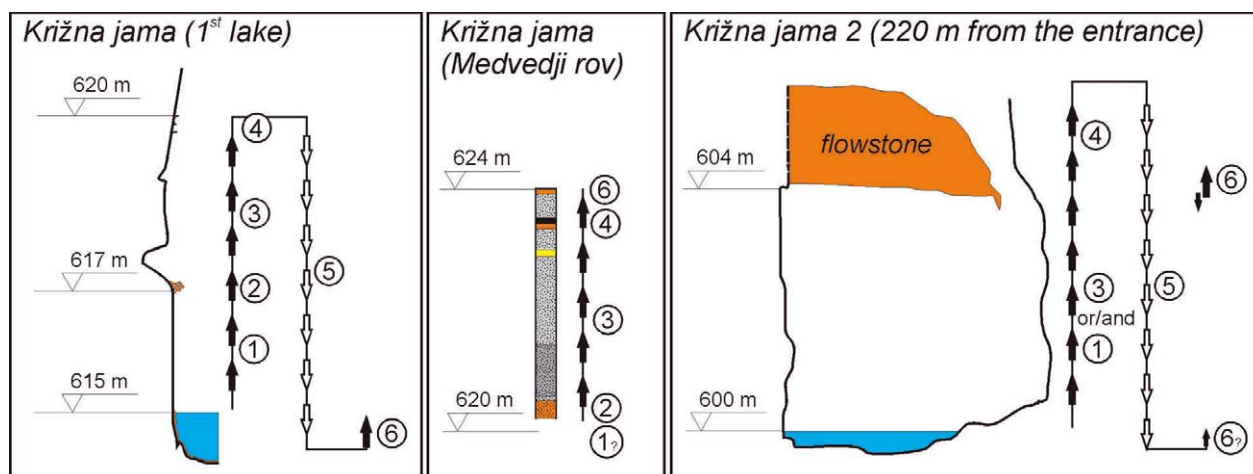


Figure 1: Sequence of sediment and most evident events in Križna jama and Križna jama 2.

(holocenska) faza je povezana z vnovičnim odlaganjem materiala – tokrat v obliki sigovih pregrad, ki so za seboj oblikovala podzemna jezera.

Ključne besede: Križna jama, speleogeneza, odlaganje sige, Slovenija

1. Fundamentals of Flowstone Deposition

Although flowstone deposition process depend on several factors, two main conditions are necessary for flowstone deposition: water has to be almost completely saturated with respect to Ca^{2+} and partial pressure of CO_2 in the water has to be higher than partial pressure of CO_2 in the cave air. When such water comes through cracks in the cave wall, degassing of CO_2 occurs. Created disequilibrium in the water leads through several chemical reactions to the precipitation of calcium carbonate. If degassing of CO_2 is strong enough and the water is not entirely saturated with Ca^{2+} , even at the beginning corrosive water become oversaturated with respect to Ca^{2+} .

Source of CO_2 for percolating water is soil cover, epikarstic and sometimes also unventilated vadose zone. Availability of carbonates for dissolution is on karst not problematic since they are common in all vertical hydrological zones (epikarstic, vadose, epiphreatic and phreatic). The strongest control on the amount of dissolved carbonates has the amount of dissolved CO_2 in the water. Concentration of dissolved CO_2 in the water usually depends on availability of CO_2 and this is strongly related to the thickness of soil and biological activity within it. Since the biological activity is a function of mean yearly temperatures, possibilities for vast flowstone deposition is the highest in warm and humid climates and the lowest in cold and dry climates. If we relate these findings to climatic variations in the Pleistocene we should conclude that major flowstone deposition is related to interglacial periods and minor to no flowstone deposition (or even corrosion) in glaciations. This interdependence was more or less successfully proved by dating of Quaternary speleothemes in the world (AT-

KINSON et al., 1986 ex WHITE, 1988; HARMON et al., 1977 ex WHITE, 1988) and also in Slovenia (MIHEVC, 2001). The same process takes place also on the surface streams (i.e. Plitvice lakes in Croatia; HORVATINČIĆ, 2008). Although some datings show that flowstone deposition also took place in glaciations (GOSPODARIČ, 1980; FORD & GOSPODARIČ, 1989), which seriously complicates simple theory. Such a growth is most likely related to warmer interstadials within ice ages or to some other factors which also influence the flowstone deposition rates. It is also possible that percolating water was so slightly oversaturated that the layers of deposited flowstone are very thin and therefore is less probable to sample them. Namely, the degree of oversaturation has a direct influence on the rate of flowstone deposition – the highest rates of flowstone deposition are observed far from equilibrium. The last period of vast flowstone deposition on Slovene lowland karst took place at the end of Würmian glaciation some 15,000 BP (MIHEVC, 2001). Flowstone deposition rate is different from place to place due to different conditions in epikarstic and vadose zone.

Flowstone deposition rate does not depend just on climate. Quantity and local distribution of deposition is strongly related to the quantity of percolating water. Therefore we could expect higher deposition rates in humid climate and no deposition in arid climate although the temperature conditions favor flowstone deposition. Quite common is also displacement of flowstone deposition areas (see profiles of studied sediments in Križna jama in GOSPODARIČ, 1980; FORD & GOSPODARIČ, 1989; ZUPAN HAJNA et al., 2008) which is probably related to hydrological and sedimentological changes in vadose and epikarstic zone. Such displacements are well recorded also on some other sites (i.e. in 3.4 Ma profile in Račiška pečina; ZUPAN HAJNA et al., 2008). Flowstone deposition is affected also by frequent floods if they occur in the time of flowstone deposition. Record of flowstone deposition can be also lost in the caves if the percolation water trickles directly into the water. Special agent is erosion and corrosion which can partly or completely remove

deposited sediments. Although the flowstone deposition is strongly related to mean outside temperature, so called flowstone generations after GOSPODARIČ (1989) should be taken cautiously. Two possible extreme situations are possible: (1) flowstone can be deposited also in glaciations but in smaller quantity and on less localities and (2) flowstone can not be deposited also during interglacials if the deposition was impeded by one of the mentioned factors.

2. Flowstone deposits in Križna jama

We have to stress at the beginning that is quite hard to determine flowstone generations since we are dealing only with few dated flowstones in Križna jama. All datations were made solely in Medvedji rov (GOSPODARIČ, 1980; FORD & GOSPODARIČ, 1989; RABEDER et al., 2001 after ZUPAN HAJNA et al., 2008; ZUPAN HAJNA et al., 2008). Elsewhere, all the chronology is made on the basis of comparison between already dated and described profile in Medvedji rov and speleogenesis in the main hydrologically active passages. This method was already used by GOSPODARIČ (1974) and it is the only possible method with very limited amount of data at this moment. There-

fore it is necessary to deal with the whole speleogenesis instead of limited study of chronologically dated flowstones. According to detailed study of allochthonous sediment in Križna jama, GOSPODARIČ (1974) observed several evident phases in Križna jama. From 1st lake to the end of Pisani rov he found out:

- Phase of passage formation,
- Phase of gravel, sand and loam accumulation,
- Phase of flowstone deposition,
- Phase of erosion and deepening of passages,
- Phase of frequent flooding and
- Phase of present-day flowstone deposition.

Although Križna jama 2, which is practically the continuation of Križna jama, was not known in Gospodarič's time, recent observation in (at least) the upstream part of Križna jama 2 indicates nearly the same sequence of phases. The cave is characterized by 4–5 m of allochthonous deposits, which were later covered by massive flowstone deposits. Flowstone deposition was so extensive in some parts that covered almost all passage's width in now hy-

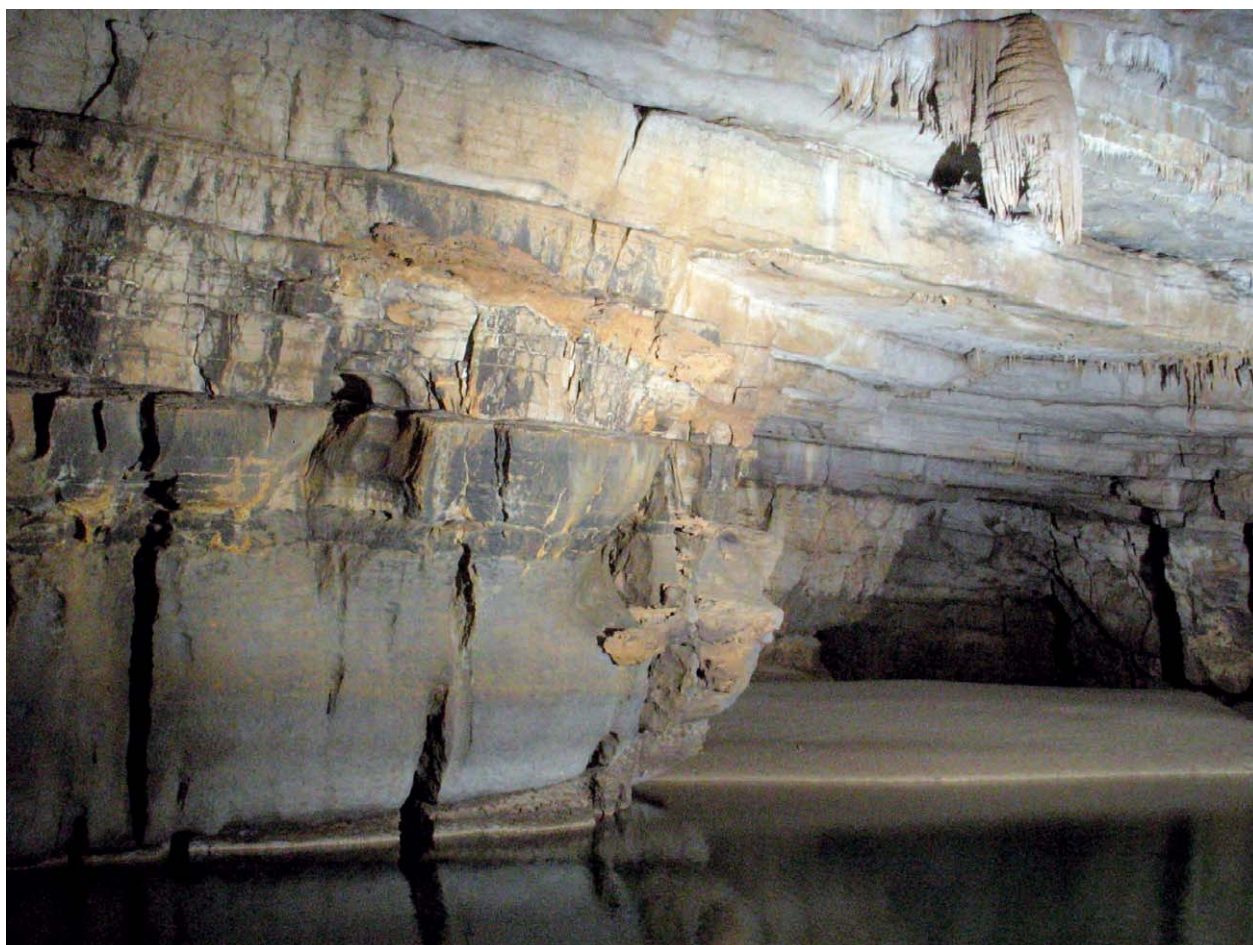


Figure 2: Preserved sediment from the Phase 1 and 3 cemented with flowstone most likely in Phases 2 and 4 at the wall of 1st lake. Findings of cave bear bones in the channel across 1st lake proof that cave bears crossed once dry area of 1st lake without problem.



Figure 3: Entrenchment of primary phreatic channel between 1st and 2nd lake in Phase 5. Limestone walls were partly covered by sand and gravel from the Phase 1 (left at the corrosional shelf), cemented in Phase 2 and therefore protected against corrosion in Phase 5.

hydrologically active passage. In that time, water flow had to be extraordinarily rare, maybe even absent and moved to lower passages. Later flowstone deposition was replaced by erosion which removed allochthonous sediment below flowstone deposits and transformed them into baldacchino canopy. Erosion was followed by present-day flowstone deposition that added some stalactites at the edges of old baldacchino canopies.

Practically identical sequence of events was recognized by GOSPODARIČ (1974) at the 1st lake. It was compared with sequence of sediments in Medvedji rov and some ages were already proposed in that time. Later progress in speleology and subsequent datations in Križna jama (FORD & GOSPODARIČ, 1989) pointed out that Gospodarič's ages are probably underestimated and that should be older. Recent observations in Križna jama also indicated an additional phase within phase of gravel, sand and loam accumulation. Since the formation of big horizontal passages (as they are extensively found in Križna jama) demands much longer period of stable conditions that was thought in Gospodarič's time and since we lack evidences from this period, we excluded the early phase of cave development from further discussion. Therefore we took into account 6 phases (Fig. 1) which are due to lack of

integral speleological research maybe too simplified but they reflect the main events in the underground system of Križna jama - Križna jama 2.

2.1. Phase 1

The oldest provable phase in Križna jama is period of gravel and sand sedimentation from the end of Pisani rov to the 1st lake all along Jezerski/Glavni rov. Allochthonous sediments were deposited at least 1–3 m above recent water level and such accumulation formed at least two sumps in Glavni/Jezerski rov (at the place of 2nd lake and between Beneški pristan and Otok) and at least one sump in Pisani rov (near Kalvarija). Therefore current of air, as it is known today, was absent in Križna jama. Passage that pass by Ponor was also filled close or completely to the roof. This resulted in either sump or completely blocked passage. Hydrological function of Medvedji rov in that time is not known yet since none of the profiles in Medvedji rov do not reach the upper limit of gravel/sand accumulation near 1st lake (617 m a.s.l.). Sediments from this altitude can not be seen without drilling also in 4.5 m deep analyzed profile Križna jama 2 in Medvedji

rov (ZUPAN HAJNA et al., 2008). Due to higher roof in Medvedji rov (in comparison with passage passing by Ponor) Medvedji rov seems to be more suitable for water flow. Transport of gravel was probably accompanied with high-velocity and corrosive water, which resulted in scalloped walls. Since the scallops are visible in lower part of cross section in Medvedji rov, this passage was active during gravel transport. Latter flooding of Medvedji rov could not produce scallops since the water velocity was much smaller. The only gravel found in Medvedji rov is microconglomerate in the profile Križna jama 2 (ZUPAN HAJNA et al., 2008), which is dislocated from the primary location and therefore fallen from the upper wall of Medvedji rov. Water course in Phase 1 could flow through Cerarjeva dvorana since we observed scallops at similar altitude as in Medvedji rov.

Catchment area of the brook was definitely on Bloke plateau since the chert and Upper Triassic dolomite found in underground sediments derive from northern part of Bloke plateau. Although there were certainly some tributaries of vadose water, streamy water was not oversaturated with respect to calcite and therefore could not cement the gravel/sand. This is a reason for extensive erosion of gravel and sand partly already during Phase 1 but especially during Phase 5. Accumulation of gravel and sand stayed at its primary position only at places where they were cemented by oversaturated percolating water (on Fig. 2 middle part of photo 1.5 m above water level). Elsewhere, the gravel/sand accumulation was highly erodible. High erodibility of gravel and sand is seen also near Ponor, where several wall notches developed due to different water level above sediments.

It is not entirely clear in which time Phase 1 took place. It is definitely older than the oldest dated flowstone layer in Profile I in Medvedji rov (146 ka B.P.; FORD & GOSPODARIČ, 1989) and most probably younger than 780 ka B.P. (= maximum age of paleomagnetically dated sediments 3.7 m deep in the profile Križna jama 2; ZUPAN HAJNA et al., 2008). Therefore the accumulation can not occurred in Würm glacial; it could be placed in early Riss or even Mindel glacial.

2.2. Phase 2

This phase of flowstone deposition is poorly visible in Križna jama since it was followed by strong erosion and corrosion in Phase 5. In other parts (i.e. in Medvedji rov) flowstone deposition is covered by younger sediments. It is exposed in Medvedji rov, 2 m above water level in 1st lake, 2 m high between 1st and 2nd lake, in Jezerski/Glavni rov near Kalvarija, upstream from Križna gora, in Matjažev rov and Koralni rov. With some uncertainty we could place in this period also cementation of gravel in Pisani rov near Matjažev rov already described by GOSPODARIČ (1974:355). Phase 2 is usually visible as cementation of already deposited gravel and sand in the Glavni/Jezerski rov and fine sands in Medvedji rov. This is probably the oldest recorded phase of flowstone deposition in Križna jama.

2.3. Phase 3

Near 1st lake we can see about 3 m high accumulation of sandy loam (Fig. 2) which filled passages to the height of 620 m a.s.l. Transportation of gravel was finished since we can not find the gravel above 617 m a.s.l. The change in sedimentation was caused by hydrological, geomorphological and climatological changes in the catchment area. Most likely all these factors reduced the quantity and velocity of water that was flowing through Križna jama. According to present-day position of drainage network it is possible that watercourse moved to well-developed northern water flow while Križna jama was affected only by seasonal floods. Redirection of water flow could be a result of extensive gravel/sand accumulation in Križna jama or reactivation of Bloščica ponors near settlement Velike Bloke. Definitely, influx of sand and gravel was strongly reduced in Križna jama. Medvedji rov was often affected by flood water since we can observe almost 3 m deep sequence of silt and clay in profile Križna jama 2 (ZUPAN HAJNA et al., 2008). Passage by Ponor was most likely sedimented to the roof and therefore impassable. The access to Medvedji rov was possible from the side of Cerarjeva dvorana. The best preserved sediments from this phase are preserved 5 m above water level of 1st lake. We have only one broad-time datation from this phase at the moment. According to ZUPAN HAJNA et al. (2008) and FORD & GOSPODARIČ (1989), who analyzed slightly younger sediments, sedimentation of silt and clay is older than 156 ka B.P. but definitely younger than 780 ka B.P.

2.4. Phase 4

In Križna jama and Križna jama 2 we can recognize the period of very rare or even absent water flow. Both caves were probably flooded only by exceptionally high waters which slightly washed away silty and clayey sediments. This happened in Phase 4 which can be characterized also by huge flowstone deposits. Occasional floods are reflected as layers of clay within contemporary flowstone deposits. If the floods would occur frequently, flowstone deposition could not be possible in the water channel (as can be seen in vast flowstone deposits in the upstream part of Križna jama 2) or the density of clayish layers would be higher (as can be seen in vast flowstone deposits in Jezerski/Glavni rov near Kalvarija). According to dating and flowstone thickness this period was relatively long and very suitable for flowstone deposition.

Since huge accumulation of gravel, sand, silt and clay filled up some parts of Križna jama already in the Phase 3, there was no air flow through the cave. Due to such meteorological and hydrological conditions Križna jama seems to be very suitable for hibernation of *Ursus spelaeus*. Since we found bones and traces of rubbing also on the right side of present-day lake (Fig. 2), Phase 4 is the only period when cave bears could cross "1st lake". Exceptionally high waters flooded bear's lair and resedimented bones of cave bear downstream or to the side passages. Medvedji

rov was not strongly affected by Phase 4, Phase 5 or Phase 6 since majority traces of cave bear's rubbing nearly correspond to present-day situation. The only deviation is at dropout dolines in Medvedji rov and in side passage on the right side of 1st lake, where the traces of rubbing are more than 2 m above depression's bottom. According to U/Th-datations (FORD in GOSPODARIČ, 1989), which were done in Medvedji rov, phase of flowstone deposition started slightly more than 146 ka B.P. and finished 126 ka B.P. with more intense flooding. If the bear bones were redeposited, they should be older than 146 ka B.P. or, accordingly to ¹⁴C datations (POHAR et al., 2002), 46.7 ± 2.4/-1.8 ka old. Gospodarič was skeptical about previously defined high ages but all result of additional U/Th dating made by FORD & GOSPODARIČ (1989) showed ages more than 116 ka B.P.

2.5. Phase 5

Traces of erosion and corrosion are observed in all hydrologically active passages in Križna jama. Passage between 1st and 2nd lake is entrenched for more than 1 m (Fig. 3), similar entrenchment is hidden below flowstone floors between 1st lake and Ponor but the most evident and widespread corrosional features are scallops. However, it is of special interest that corrosion is absent or very low nowadays in Križna jama also at high water levels (PRELOVŠEK et al., 2008). Therefore the majority of corrosional features have to be fossilized remnants of chemically different past water flow before Holocene. In Phase 5 we observe also vast erosion of previously accumulated sediments. The latter were preserved only in side passages but even there they were partly removed when the dropout doline formed (for example in Medvedji rov). At 1st lake more than 6 m of sediment was washed away. This is the reason that we can found some fragments of cave bear bones also in Križna jama 2 – they were transported along underground water flow.

Beginning of this period started about 126 ka B.P. after FORD & GOSPODARIČ (1989) and lasted to about 15 ka B.P. According to more than 1 m deep entrenchment between 1st and 2nd lake in this time, corrosion rate was about 0.01 mm/a. If we take into account ages acquired by POHAR et al. (2002), corrosion rate should be 0.04 mm/a.

2.6. Phase 6

The youngest (present-day) phase started around 10–15 ka B.P. In this time Križna jama is characterized by water rich in CO₂ and therefore in dissolved calcium carbonate. Especially in winter time water of the main stream becomes highly oversaturated (PRELOVŠEK, 2007) but the percolating water is oversaturated probably all through

the year. Growth of rimstone dams was measured by MIHEVC (1997) to 0.1 mm/a below 1st lake. Flowing water produced rimstone dams all along Pisani rov, Blata passage and Jezerski/Glavni rov, while the percolating water produced stalagmite Čimboraso, stalagmite on the southern bank of 1st lake, flowstone coating of slope above Kittlova brezna and famous submerged stalagmites and columns at the Beneški pristan. Below this flowstone the majority of cave bear bones were found. Stalagmites are often elongated especially at narrow passages. This is related to air current which was possible after erosion of sediments at very low passages. In this time flowstone blocked the passage between Medvedji rov and Cerarjeva dvorana. In the case of high water, which can rise up to 4 m above ordinary water level to the altitude up to 620 m a.s.l., fine calcite sand, silt and clay is deposited in side passages.

3. References

- FORD, D. & GOSPODARIČ, R., 1989. U series dating studies of *Ursus spelaeus* deposits in Križna jama, Slovenia. — *Acta carsologica*, 18:39–51, Ljubljana.
- GOSPODARIČ, R., 1974. Fluvialni sedimenti v Križni jami. — *Acta carsologica*, 4:325–366, Ljubljana.
- GOSPODARIČ, R., 1980. Generacije sig v klasičnem krasu Slovenije. — *Acta carsologica*, 9:87–110 Ljubljana.
- HORVATINČIČ, N., 2008. Tufa as a karst phenomena: environmental and paleoclimate conditions of tufa formation. — 16th International Karstological School »Classical Karst«, Karst sediments, Postojna (guide book), p. 76.
- MIHEVC, A., 1997. Meritve hitrosti rasti sige na pregradah v Križni jami. — *Naše jame*, 39:110–115.
- MIHEVC, A., 2001. Speleogeneza Divaškega krasa. — Založba ZRC, Ljubljana, 180 pp.
- POHAR, V., KRALJ, P., RABEDER, G., MISIC, M., 2002. Cave sediments and fossil mammal remains in Križna jama, Southern Slovenia. — [in:] Cave-Bear-Researches/Höhlen-Bären-Forschungen. — Abhandlung zur Karst- und Höhlenkunde, 34:49–51.
- PRELOVŠEK, M., 2007. Križna jama – smaragdna jezera za sigovimi pregradami. — *Proteus*, 70/4:159–166 Ljubljana.
- PRELOVŠEK, M., TURK, J., GABROVŠEK, F., 2008. Hydrodynamic aspect of caves. — *International Journal of Speleology*, 37/1:11–26, Bologna.
- WHITE, W.B., 1988. Geomorphology and Hydrology of Karst Terrains. — Oxford University Press, New York/Oxford, 322 pp.
- ZUPAN HAJNA, N., MIHEVC, A., PRUNER, P., BOSAK, P., 2008. Paleomagnetism and magnetostratigraphy of karst sediments in Slovenia. — Založba ZRC/ZRC Publishing, Ljubljana - Postojna, 266 pp.