MITTEILUNGEN DER KOMMISSION FÜR QUARTÄRFORSCHUNG
DER ÖSTERREICHISCHEN AKADEMIE DER WISSENSCHAFTEN

Band 21 / Volume 21

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Palaeontology, Zoology and Geology of Križna jama in Slovenia

Martina Pacher, Vida Pohar & Gernot Rabeder (eds.)

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Eigentümer und Verleger: Österreichische Akademie der Wissenschaften

Herausgeber: Prof. Dr. Gernot Rabeder für die Kommission für Quartärforschung der Österreichischen Akademie der Wissenschaften, Institut für Paläontologie der Universität Wien, Geozentrum, Althanstraße 14, A-1090 Wien, Österreich.

Layout und Satz: Dr. Gerhard Withalm, Institut für Paläontologie der Universität Wien, Geozentrum, Althanstraße 14, A-1090 Wien, Österreich.

Druck und Bindung: Prime Rate kft., Budapest

Veröffentlicht mit Unterstützung des
Austrian Science Fund (FWF): PUB 152-B19

FWF Der Wissenschaftsfonds.

ISBN 978-3-7001-7672-5

Verlag der Österreichischen Akademie der Wissenschaften
Tel.: +43-1-51581-3402, Fax +43-1-51581-3400
Postgasse 7, A-1010 Wien

E-Mail: verlag@oeaw.ac.at
http://hw.oeaw.ac.at/7672-5
http://verlag.oeaw.ac.at

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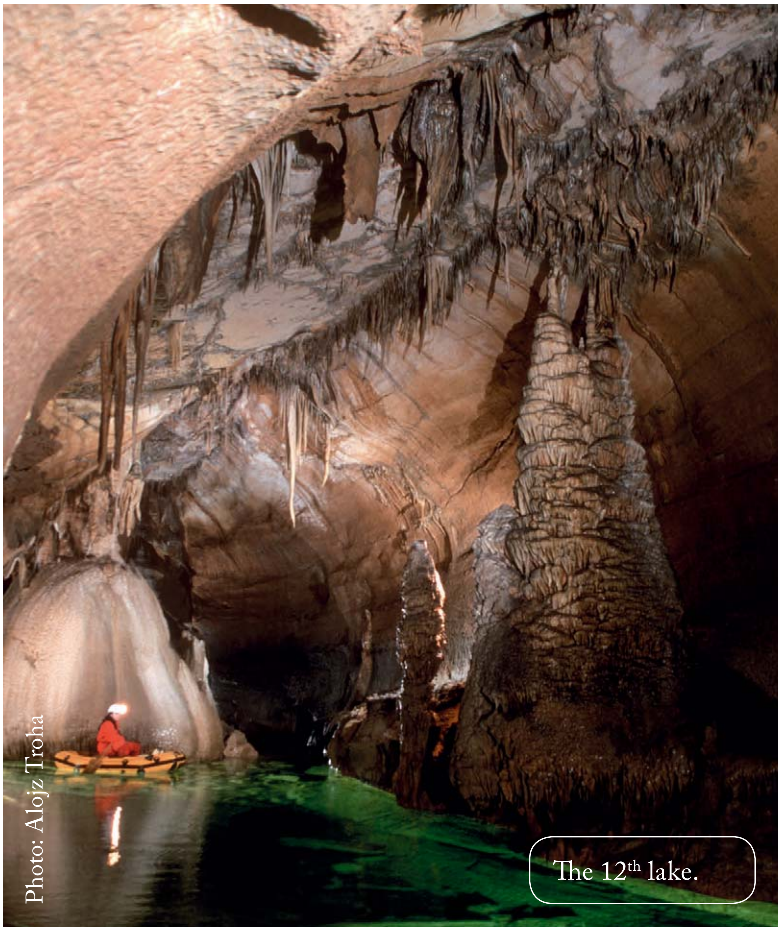
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ZUSAMMENFASSUNG

Die Křižna jama (Kreuzberghöhle) bei Lož (Laas) in Slowenien zählt zu den größten und schönsten Höhlen des „Klassischen Karstes". Sie besteht aus imposanten Hallen mit kolossalen Tropfsteingebilden sowie Wasser führenden Gängen, die ebenfalls mit herrlichen Sinterfiguren geschmückt sind. In den eingangsnahen Hallen – etwa 60 Meter über dem heutigen Bachniveau – stießen schon die ersten Besucher um 1830 auf massenhaft herumliegende Reste von Höhlenbären, die hier vor ca. 40.000 Jahren gut geschützte Überwinterungsplätze vorgefunden haben. Die großen Ansammlungen der fossilen Knochen und Zähne sowie die relativ gute Erreichbarkeit haben schon im Jahre 1878 Forscher aus Wien angelockt (Pohar, Křižna jama: Description...), die aus dem lockeren Lehm große Mengen von gut erhaltenen Schädeln, Kiefern und Knochen bergen und nach Wien bringen konnten. Die Ergebnisse wurden vom Leiter der Grabungen, Ferdinand von Hochstetter im Jahre 1881 in den Denkschriften der kaiserlichen Akademie der Wissenschaften in Wien publiziert.

Die Kreuzberghöhle ist auch eine der zoologisch interessantesten Höhlen der Welt. Sie wurde schon ab 1850 intensiv von Zoologen untersucht, weil sie besonders reich an Troglobionten, das sind Tierarten, die zeitlebens nur in der Höhle leben, ist. Sie wurde Typuslokalität für acht aquatische und drei terrestrische Taxa: *Belgrandiella crucis*, *B. schleschi* und *Zospeum exiguum* (Gastropoda), *Rhyacodrilus omodeoi* (Oligochaeta), *Niphargus orcinus* (Amphipoda), *Manolistra racovitzai* (Isopoda), *Bathyscimorphus trifurcatus*, *Typhlotrechus bilimeki frigens* und *Anophthalmus heteromorphus* (Coleoptera). Der Artikel von Sket & Stoch (Recent Fauna of the Cave Křižna jama..., p. 45 ff.) gibt einen Überblick des heutigen Forschungsstandes.

Eine so große Wasser führende Höhle ist natürlich auch für geologische, spelaeogenetische und hydrogeologische Forschungsansätze von Bedeutung. Den heutigen Wissensstand präsentieren die Artikel von Knez & Prelovšek (The Geological Setting..., p. 15 ff.) und Prelovšek (a: Speleogenesis and Flowstone..., p. 21 ff., und b: The Hydrogeological Setting..., p. 27 ff.).

Der Grund für die Herausgabe dieser Monographie liegt vorwiegend in den sensationellen Funden der so genannten „Nachgrabungen" (Rabeder & Withalm, The Re-Excavations..., p. 7 ff.). Als sich herausgestellt hat, dass der Großteil der von Hochstetter et al. geborgenen Fossilien, besonders die vielen Schädel und Mandibel, die am Naturhistorischen Museum in Wien aufbewahrt waren, nicht mehr auffindbar sind, wurde in Kooperation der Universitäten Ljubljana und Wien ein Grabungsprojekt gestartet, das in den Jahren 1999 und 2001 nicht nur die Proben für die sedimentologischen, stratigraphischen und chronologischen Analysen brachte (Kralj, Sedimentary Deposits..., p. 35 ff.) sondern auch sensationelle Funde von Bärenschädeln aus dem Fundbereich „Kittls Bärenhöhle". Nach dieser Aktion lag nun auch genügend Fossilmaterial vor, um die systematische Stellung der Höhlenbären zu klären. Es handelt sich um eine großwüchsige Höhlenbärenart (*U. ingressus* Rabeder et al., 2004), die wahrscheinlich vor 50.000 Jahren aus dem Osten nach Mitteleuropa eingewandert ist und zum ersten Mal aus der Gamssulzenhöhle im Toten Gebirge (Oberösterreich) beschrieben wurde. Die Mehrzahl der Artikel widmet sich der Beschreibung und Analyse der Bärenreste. Aus den metrischen und morphologischen Daten der Backenzähne wird auf ein sehr hohes Evolutionsniveau geschlossen, wie es nur bei den Faunen der *Ursus ingressus*-Gruppe vorkommt (Rabeder: Metrics and Evolutionary Level..., p. 65 ff.). Zu ganz ähnlichen Ergebnissen kommen Pappa (The Study of Cave Bear Milk Teeth..., p. 73 ff.), Frischauf (The Cave Bear Incisors..., p. 83 ff.) und Withalm (Analysis of the Cave Bear Metapodial Bones..., p. 125 ff.) durch die Bearbeitung der Milchzähne, der Schneidezähne und der Metapodien, sowie Pacher (Skeletal Element Distribution..., p. 93 ff.) durch die Analyse der Schädel, Mandibeln und der postkranialen Elemente. In der Bärenassoziation der Křižna jama überwiegen die männlichen Individuen, das geht vor allem aus der Größenverteilung der Eckzähne hervor (Rabeder & Withalm: Sexual Dimorphism..., p. 117 ff.). Ontogenetische Studien belegen, dass die Mehrzahl der in der Höhle nachgewiesenen Tiere während des Winterschlafs gestorben sind. Das höchste Lebensalter, das die Bären erreicht haben lag bei 28 Jahren (Debeljak: The Age and Sex Structure..., p. 105 ff.).

Neben den Bärenresten, die über 99% des paläontologischen Fundgutes ausmachen, gibt es einige Funde von Säugetieren, welche die so genannte „Begleitfauna" ausmachen: *Martes martes*, *Canis lupus* und *Gulo gulo* (Pacher & Döppes, Additional Faunal Elements..., p. 57 ff.). Diese Funde stammen aus den „Altgrabungen" unter F. v. Hochstetter. Deren interessantestes Taxon ist *Gulo gulo*, der Vielfraß. Dieses heute nur in der Arktis lebende Raubtier war im Mittel- und Jungpleistozän auch in den Gebieten südlich der Alpen verbreitet. Schließlich konnte auch die Altersstellung der Höhlenbärenreste durch einige Radiokarbondatierungen (Rabeder, Withalm & Wild (Stratigraphy and Chronology..., p. 131 ff.) geklärt werden, sie stammen aus der Mittelwürm-Warmzeit.

SUMMARY

The Križna jama near Lož in Slovenia is one of the biggest and most beautiful caves of the Classic Karst. The cave consists of impressive halls with colossal dripstone formations, as well as hydrous corridors that are also decorated with sinter- and flowstone figures. It was back in 1830 that first visitors came across the remains of a massive amount of cave bears that found a well protected place to hibernate about 40.000 years ago in the corridors near to the entrance, about 60 meters above the recent stream level. The large fossil assemblage consisting mainly of teeth and bones, as well the good reachability attracted scientists from Vienna in 1878, to excavate the fossils out of the unconsolidated clay. Later the large amount of skulls, jaws and bones, has been brought to Vienna and were stored in the Museum of Natural History. The results have been published by the head of the excavation, Ferdinand von Hochstetter in 1881 in "Denkschriften der kaiserlichen Akademie der Wissenschaften" in Vienna. Also from the Zoological point of view, Križna jama is one of the most interesting caves in the world. Since 1850 the cave has been intensively researched by zoologists because of its troglobionts, organisms that live exclusively in caves.
Križna jama is the type locality for eight aquatic and three terrestrial taxa: *Belgrandiella crucis*, *Belgrandiella schleschi* und *Zospeum exiguum* (Gastropoda), *Rhyacodrilus omodeoi* (Oligochaeta), *Niphargus orcinus* (Amphipoda), *Manolistra racovitzai* (Isopoda), *Bathyscimorphus trifurcatus*, *Typhlotrechus bilimeki frigens* und *Anophthalmus heteromorphus* (Coleoptera). The article written by Sket & Stoch (Recent Fauna of the Cave Križna jama..., p. 45 ff.) provides us with an overview on the current state of research. Such a large hydrous cave is of course important for geological, speleogenetic and hydrogeological research. The actual state of research is presented in the article from Knez & Prelovšek (The Geological Setting..., p. 15 ff.) and Prelovšek (a: Speleogenesis and Flowstone..., p. 21 ff., and b: The Hydrogeological Setting..., p. 27 ff.).
The reason for the release of this monograph is mostly due to the sensational discoveries of the so-called additional excavations (Rabeder & Withalm: The Re-Excavations 1999..., p. 7 ff.). Later we found out that most of the remains that have been stored at the Museum of Natural History in Vienna, especially skulls and jaws excavated by Hochstetter, could not be found anymore, and we started a cooperation between the Universities Ljubljana and Vienna for an excavation project. During the years 1999 and 2001 these excavations provided us not only with the samples for the sediment analysis, stratigraphy and chronology (Kralj: Sedimentary Deposits..., p. 35 ff.) but also with sensational findings of cave bear skulls from a part called "Kittl's Bärenhöhle". After the campaign there was enough fossil material to clarify the systematic position of the cave bears. We are dealing with *Ursus ingressus* Rabeder et al., 2004, the cave bear with the largest growth within the cave bear group, that most likely migrated 50.000 years ago from the east to middle Europe and has been described from the Gamssulzenhöhle in the "Totes Gebirge" (Upper Austria) for the first time.
The metrical and morphological data of the molars give a very high evolutionary level that occurs only in the faunas of the *Ursus ingressus*-Group (Rabeder: Metrics and Evolutionary Level..., p. 65 ff.). The quite same results Pappa (The Study of Cave Bear and Evolutionary Level..., p. 73 ff.), Frischauf (The Cave Bear Incisors..., p. 83 ff.), and Withalm (Analysis of the Cave Bear Metapodial Bones..., p. 125 ff.), appear per the analysis of deciduous teeth, incisors and the metapodials, the same Pacher (Skeletal Element Distribution..., p. 93 ff.) through the studies of skulls, jaws and the postcranial elements. Due to the size distribution of the canines from Križna jama (Rabeder & Withalm: Sexual Dimorphism..., p. 117 ff.), it is visible that the male individuals dominate. Ontogenetic studies prove that the majority of the assured animals in the cave, died during their hibernation period. The highest lifespan of the bears reached 28 years (Debeljak: The Age and Sex Structure..., p. 105 ff.).
Beside the cave bear remains that make up approximately 99% of the paleontological findings, a few other mammals have been found: *Martes martes*, *Canis lupus* and *Gulo gulo* (Pacher & Döppes: Additional Faunal Elements..., p. 57 ff.). These findings date back to the excavations by Ferdinand von Hochstetter. The most interesting taxon is of course *Gulo gulo*, the wolverine. In present times, this carnivore lives only in the arctic region, and during Middle- and Late- Pleistocene it was widespread in the Southern Alps as well. And last but not least it was possible to determine the chronological position of the cave bear remains by means of several ^{14}C-datings (Rabeder, Withalm & Wild: Stratigraphy and Chronology of..., p. 131), which showed that the bears hibernated in Križna jama during the Middle-Würmian Warm Interval.

Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:1 – 6, Wien 2014

Križna jama: Description and History of Research

by

Vida Pohar [1)]

Pohar, V., 2014. Križna jama: Description and History of Research. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:1 – 6, Wien.

Zusammenfassung

Die Križna jama ist seit dem Jahr 1832 bekannt. Eine erste Beschreibung der damals bekannten Teile der Höhle und ihrer Höhlenbären-Fundstellen erfolgte einige Jahre später und beinhaltete auch einen skizzenhaften Plan. Es war an Ferdinand von Hochstetter vom Naturhistorischen Museum Wien, dem ehemaligen k.k. Hof-Naturalien-kabinett, die ersten Ausgrabungen in der Križna jama in den Jahren 1878 und 1879 durchzuführen. Es dauerte in etwa 50 weitere Jahre bis die Höhle von Mitgliedern des Höhlenforscher-Verbandes in Laibach komplett vermessen wurde. Die neusten Ergebnisse zu Geologie und den allochthonen Höhlensedimenten wurde in den Jahren 1968 bis 1971 hinzugefügt. Erst jüngst, es war im Jahre 1991, wurde von lokalen Höhlenforschern die so genannte „Križna jama 2" nach dem Siphon entdeckt. Sie wurde bis heute nicht der Öffentlichkeit zugänglich gemacht.
Schlüsselwörter: Križna jama, Slowenien, Geographie, Topographie, Forschungsgeschichte

Summary

Križna jama is known since 1832. A first description of the surveyed parts of the cave and its cave bear sites was published several years later, along with a sketchy map. It was upon Ferdinand von Hochstetter from the Museum of Natural History in Vienna to conduct the very first excavations in Križna jama in the years 1878 and 1879. It took approximately 50 more years until the cave was completely surveyed by members of the Society for Cave Exploration (in Ljubljana) and later on – in the years from 1968 until 1971 – the latest results concerning the geology of its surroundings as well as the description of the allochthonous sediments, their origin and distribution were added. Recently, it was in 1991, the latest part of the cave, the so called "Križna jama 2", was discovered by local people behind the siphon, see the complete map, p. 137. It is still not open to the public.
Keywords: Križna jama, Slovenia, geography, topography, history of excavations

Izvleček

Križna jama pri Ložu je ena najlepših jam klasičnega krasa v Sloveniji. Posebnost jame je več kot 40 podzemnih jezer s sigovimi pregradami preko katerih se preliva kristalno čista voda. Pregrade še vedno rastejo in z njimi vodna gladina. Narasla voda je zalila na tleh stoječe kapnike, kar daje vtis, da rastejo iz vode. Poleg številnih vodnih rovov, različno velikih podornih dvoran, ki jih krasijo razkošno oblikovane kapniške tvorbe, so tudi suhi rovi. Med njimi sta najpomembnejša Medvedji in Kittlov oziroma Cerarjev rov, saj so v njih odkrili bogata nahajališča kosti, zob in obrusov jamskega medveda. Križna jama je znana od leta 1832, nekaj let kasneje je izšel opis preiskanih rovov, nahajališča medvedjih kosti in približni načrt jame. V letih 1878 in 1879 je v Medvedjem rovu načrtno izkopaval Hochstetter. Skoraj pol stoletja kasneje so člani Društva za raziskavanje podzemskih jam (v Ljubljani) skoraj v celoti raziskali in opisali Križno jamo. V letih 1968 do 1971 so omenjenim raiskavam dodali še izsledke geoloških raziskav okolice jame in opis alohtonih jamskih sedimentov, njihov izvor in razširjenost. V novejšem času (1991 leta) so domačini za sifonom v Kittlovem rovu odkrili »Križno jamo 2«, ki pa je zaenkrat še zaprta za obisk.
Ključne besede: Križna jama, Slovenija, geografski in topografski podatki, zgodovina raziskav

1. Description

The Križna jama is situated in the southern part of Slovenia, in a position on the feeder side (SE) of the Cerkniško

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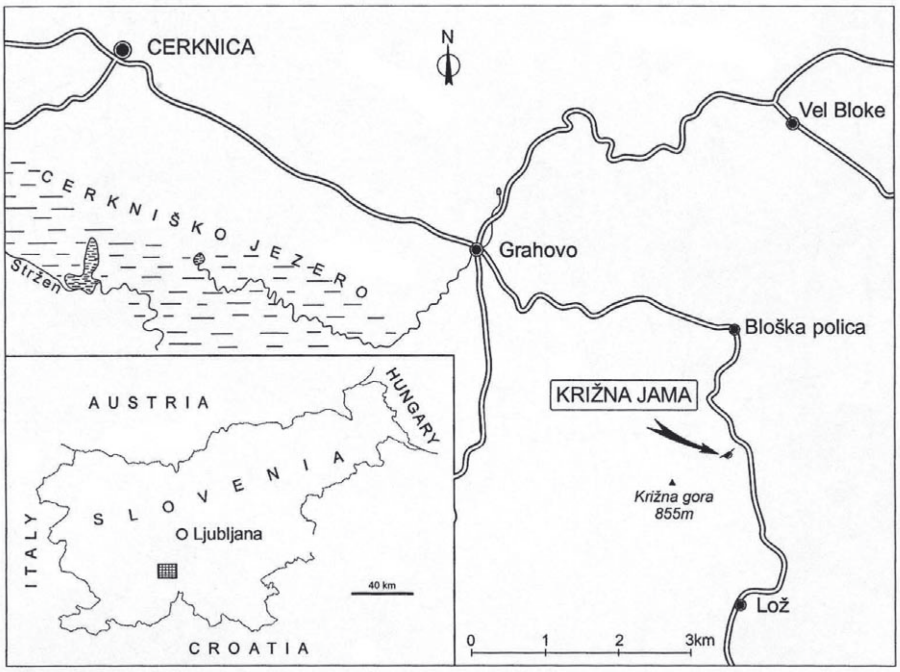
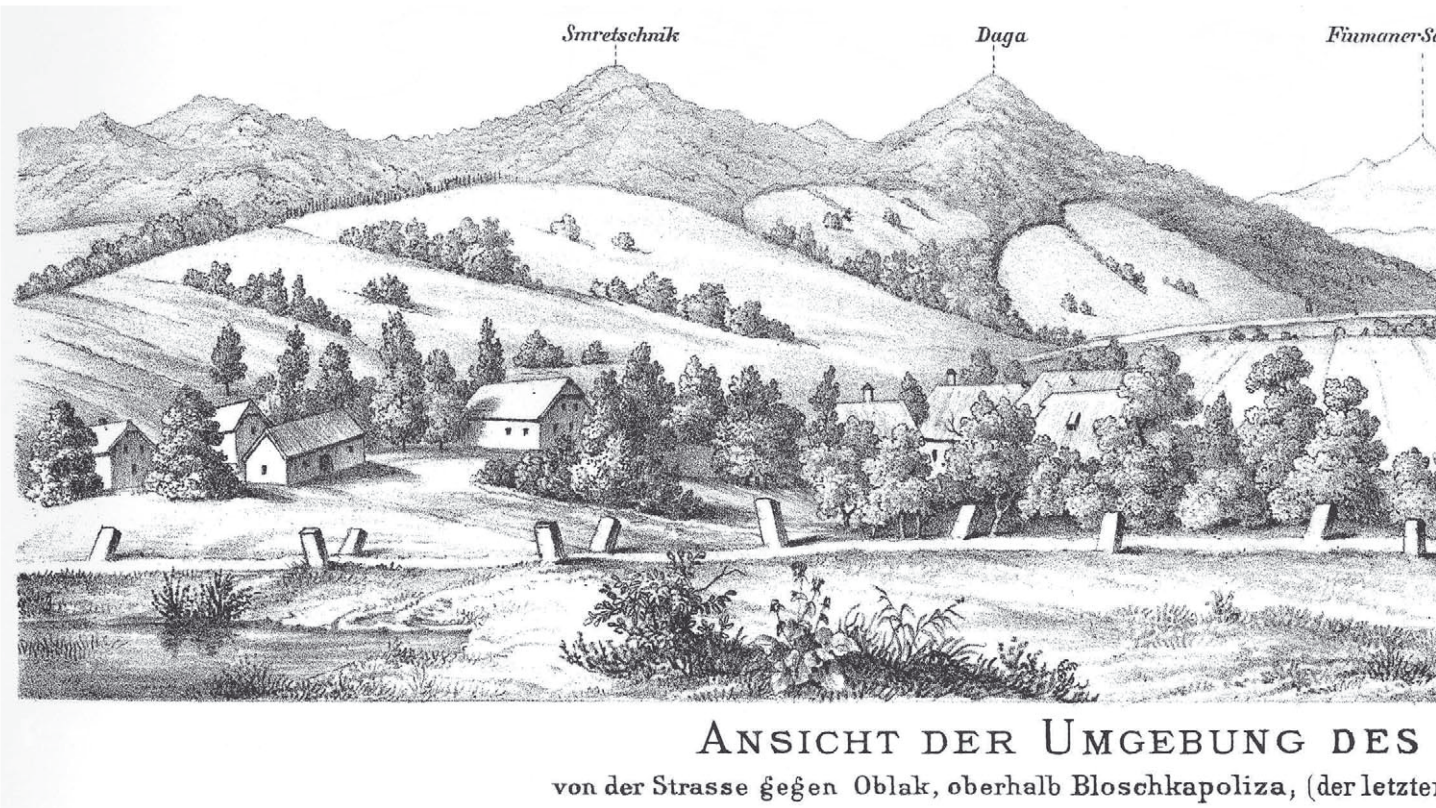


Figure 1: Geographic position of the Križna jama cave.

jezero, a temporary lake in the vicinity of the cave, and the transition from Bloke plateau to Cerkniško polje, see Fig. 1. The precipitation from Bloke plateau is collected in the cave and is flowing subsurface towards the eastern margin of Cerkniško jezero. By means of colorizing the water the cavers discovered that a part of the water from Bloke plateau does not go to Križna jama but, instead of this to a rivulet in Cerkniško dolina, called Žirovniščica, which flows into the rivulet on the Loško polje plain.
Križna jama is known since the beginning of the 19th century, amongst other reasons also for its richness in cave bear remains. Despite the huge amount of cave bear bones it was impossible for all the collectors and scientists to discover any evidence for the presence of the glacial men.

2. History of Research

It is now 160 years ago that the former forest official J. Cerar (Zörrer, 1838) published a first map of Križna



jama, a description of the cave entrance and of a part of a passage containing cave bear remains, emended by the sites where the teeth and bones were found. At first he discovered the bones close to the cave entrance and a little later he discovered the cave bear remains in the so called "Bear Cave". Only a few years after the discoveries of Cerar, it was in 1847, an article on the cave bears from Križna jama was published by A. Škofiz in no. 51 of a journal called "Illyrisches Blatt". In 1854 A. Schmidl described on p. 284 of his publication the already known bear cave in Križna jama more thoroughly and added several newly discovered sites with bear remains. Both of them, J. Cerar and A. Schmidl, described the Bear Cave in the dry part of Križna jama in detail. The latter part was excavated by F. von Hochstetter (1881) in the years 1878 and 1879. An impression what the area around Križna jama looked like is given in Fig. 2. Hochstetter and his workers (see the upper part of Plate 5) collected approximately 4600 cave bear remains (Bohinec, 1963) representing an MNI of more than 100 individuals. From these bones two skeletons were reconstructed which are on display in the Museum of Natural History in Vienna since that time.

During the aforementioned excavations I. Szombáthy (1879) surveyed the entrance part and the Bear Cave, see Fig. 3. The part in NE-SW direction he named "Bärengrotte", in Slovenian "Medvedji rov", the other one, heading firstly towards W and later towards N was named "Hochstetters Schatzkammer" (Archive of the Society for Cave Exploration, Ljubljana and Karst Research Institute ZRC SAZU). Later on, in papers dedicated to the interested people, the subterranean lakes, flowstone figures, ceiling falls and newly discovered parts of the cave were described, see Michler (1934), Šerko & Michler (1948) and Planina (1965). In 1968 and 1971 there were intensive speleological research activities in the surrounding of Cerkniško jezero and its tributaries, with Križna jama as a centre of attention. Until 1971 Križna jama was more than eight kilometres long. Gospodarič (1974) was dealing with the allochthonous (fluviatile) sediments in the cave. He described their distribution, their relation to the autochthonous sediments and their positioning in the cave. Moreover, he tried to investigate which stones were transported by the subterranean river and in which way and how they were deposited in the cave during its development. The most recent map of Križna jama dates back to 2010 and is situated at the very end of this volume and a better impression of this cave is given by means of the plates (Plates I–IX) situated before this article.

3. Description of Medvedji rov (Bärengrotte)

The scientists unearthing the cave bear remains in the Slovenian sites found not only bones and teeth, but also remains documenting the presence of Pleistocene men, i.e. tools made from bone and stone, fire places and butchering remains. M. Brodar & R. Gospodarič (1973) organized an excavation camp for the youth in 1971 to find a proof for the presence of glacial men in Križna jama. They excavated in several places in Medvedji rov and collected data on its development, the origin of the depositions and cave bear remains, but they did not find any hint for the presence of glacial men.

Nowadays, Medvedji rov is accessible via the main hall, close to the first lake, compare to Fig. 3. This is the place

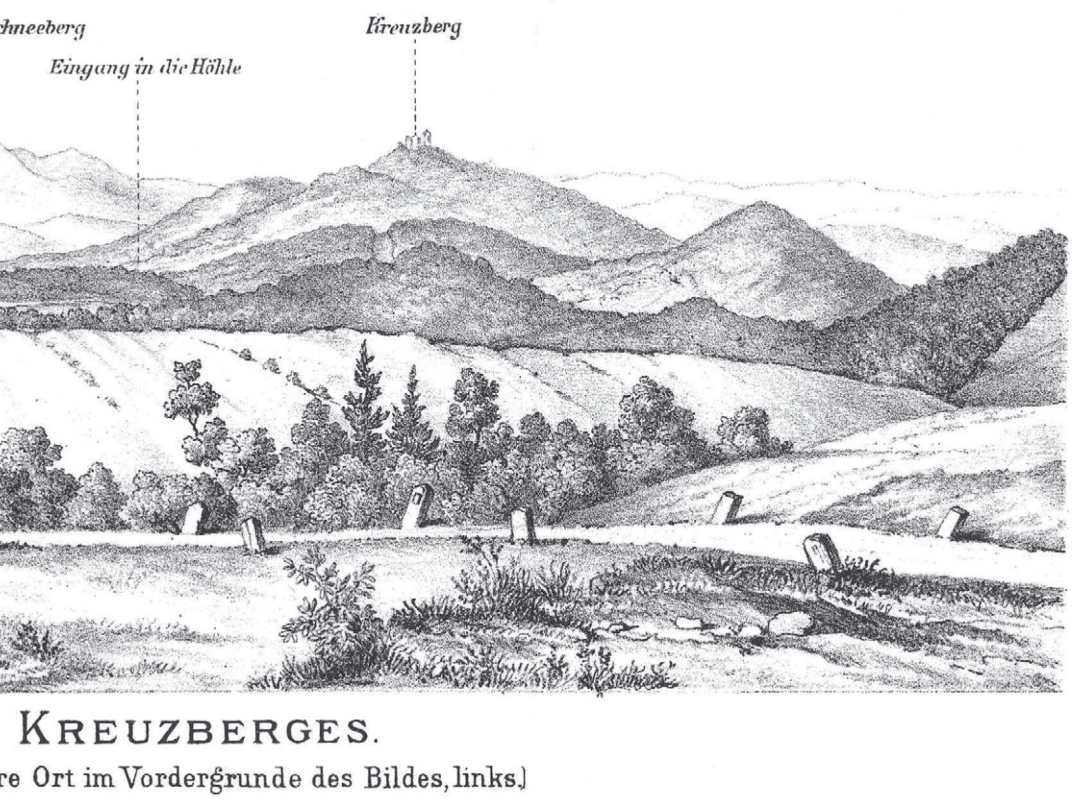


Figure 2: Panoramic view of the surroundings of Križna gora, seen from the road towards Oblak above Bloška polica, the latter village in the foreground of the picture, left. Illustration taken from Hochstetter (1881:Tafel III).

Figure 3: Ground map of the "Old Part" of Križna jama showing Hochstetter's excavation areas as well as those from the most recent excavations, map taken from Hochstetter (1881).

Please note also the folded map at the end of the volume representing the actual state of research in Križna jama.

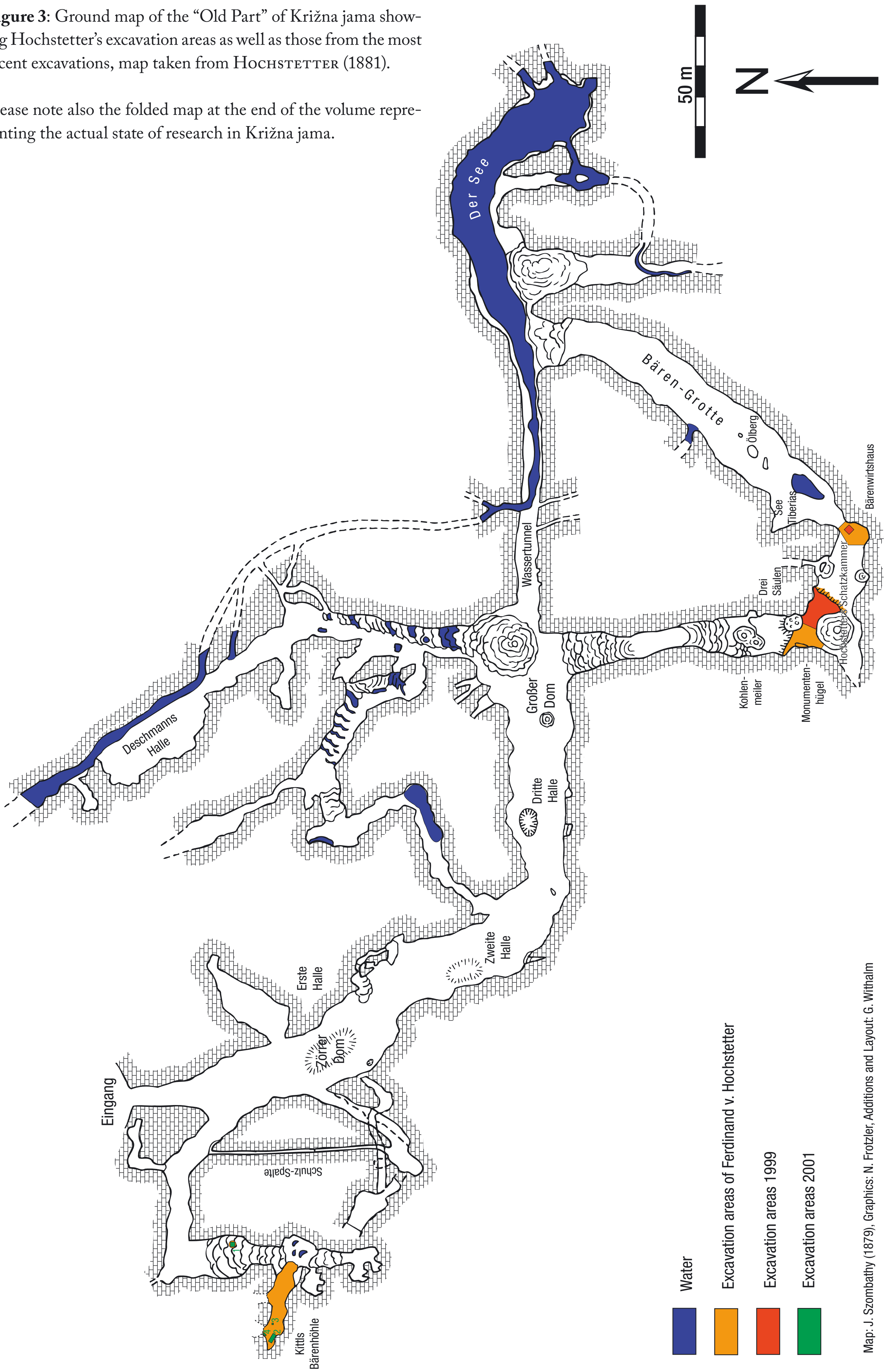
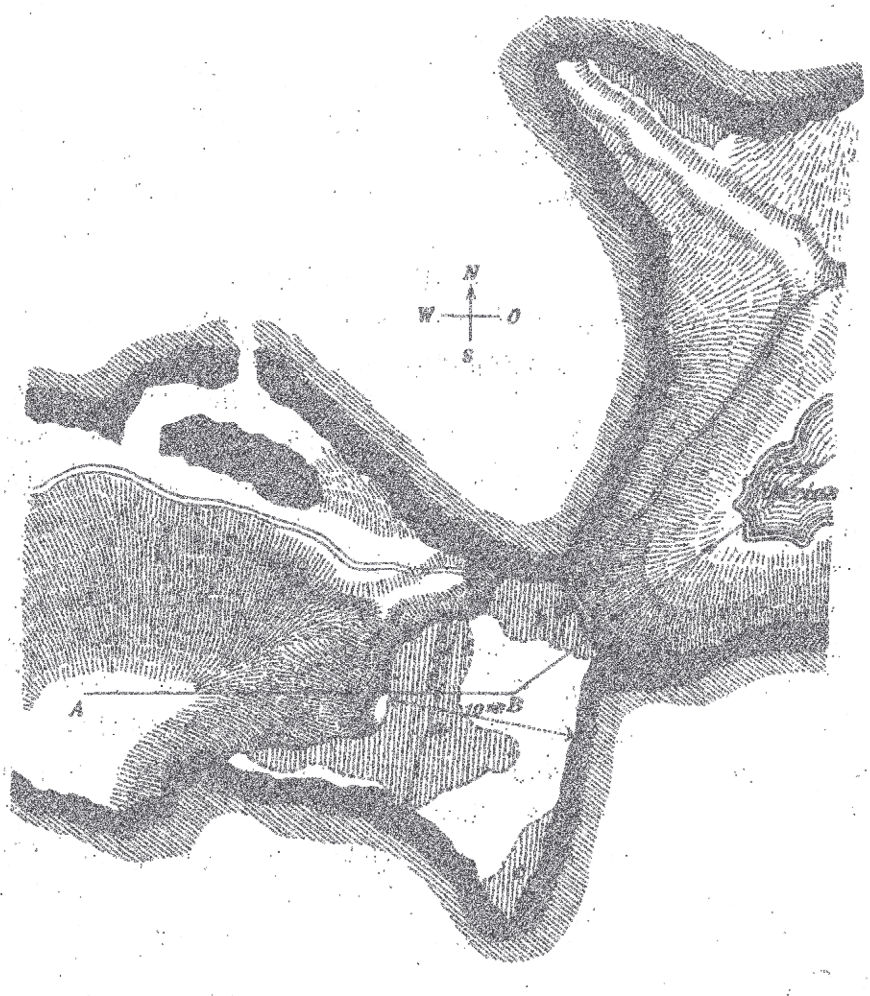


Fig. 5.



Grundriss der Lehmterrasse zum „Bärenwirthshaus".
a, b und c die 1878 und 1879 abgegrabenen Stellen.

Figure 4: Ground map of the loam terrace called "Bärenwirtshaus", which is part of Medvedji rov, taken from Hochstetter (1881:12). The small letters indicate the excavation areas from 1878 and 1879, the capitals correspond to Fig. 5.

where the subterranean river disappears at an altitude of 612 m a.s.l. Medvedji rov is situated in one meter thick layers of Jurassic limestone, inclining towards S, which is partly dolomitised. It is a dry passage, filled with sediments, flowstone and blocks. The entrance of Medvedji rov is blocked by a ceiling fall, which is partly covered by flowstone, which is formed even nowadays. Behind this hill the floor consists of loam on a level, some meters lower. According to Brodar & Gospodarič (1973:33) the following hill shows the loam at its original height, equalling 620 m a.s.l., i.e. Medvedji rov was filled with loam until this altitude so that there were only two meters between the floor and the ceiling. In former times the cave bear came not along this route, but directly from the main hall close to Čimboraso, see Fig. 3. This former entrance was blocked by the formation of flowstone in the course of the following modification of the cave at a distance of 10 m. Figure 4 shows the "Bärenwirtshaus", which is in a position between "Medvedji rov" (Bären-Grotte) in the East and "Hochstetters Schatzkammer" in the West; and Fig. 5 shows a section through "Bärenwirtshaus". The results of the excavation camp by Brodar & Gospodarič (1973) are:

Medvedji rov is 223.5 m long and contains several generations of flowstone. The allochthonous loams were deposited by calm (standing) waters of the subterranean river. Between these flooded phases were phases of flowstone formation, these flowstones were formed by water dripping from the ceiling. Of course, the cave bears entered Medvedji rov during these dry phases, because the remains were found above and below the aforementioned flowstones. Some of these bones look polished and show holes, which very likely originate from teeth of carnivores. Excavations were performed in two places and two profiles were documented:

Profile A: Its position is pitifully unknown because it is not in the map; it is only known that the distance between the two walls equals 15 m. The height of this profile was four meters and all in all six layers consisting of loam, sand and flowstone were distinguished. In both profiles, A and B, the lowermost stratum 1 consists of loam mixed with sand, which is covered by a layer of

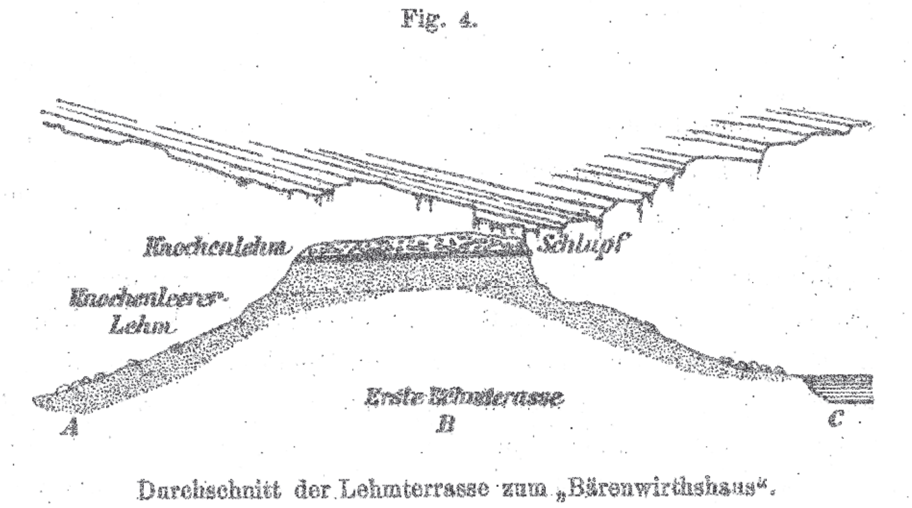


Figure 5: Longitudinal section through the loam terrace called "Bärenwirtshaus", taken from Hochstetter (1881:11). The capitals A to C in this figure correspond to the ones in Fig. 4.

flowstone, stratum 2. Above this flowstone there is a layer of reddish-brown loam of approximately 50 cm height (stratum 3) which bears some cave bear remains. Above this layer there is a plain horizon of light-grey flowstone consisting of big crystals which form the base for stalagmites of approximately 50 cm height. This is stratum 4. The following layer consists of reddish loam which shows the highest abundance of cave bear remains, stratum 5. Stratum 6 is a layer of flowstone which, on one hand, can reach a height of up to 60 cm, but, on the other hand is partially inexistent simply because it was not formed at all. This enabled the first visitors of Medvedji rov to find cave bear remains on the floor they were standing on.

Based on the fact that the cave bears in Slovenia got extinct after the Last Glacial Maximum (LGM), Gospodarič concludes that stratum 3 was formed during the elder Wurmian (W I), stratum 5 was formed during the first cold peak of the younger Wurmian (W II). According to ^{230}Th/^{234}U-datings of samples taken from strata 2 + 4, the intercalating loams, strata 3 + 5 are approximately 146,000 ± 14,000 a and 126,000 ± 11,000 a old, see Ford & Gospodarič (1989:51).

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The Re-Excavations in Križna jama in 1999 and 2001 (Slovenia)

by

Gernot Rabeder [1)] & Gerhard Withalm [2)]

Rabeder, G., Withalm, G., 2014. The Re-Excavations in Križna jama in 1999 and 2001 (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:7 – 13, Wien.

Zusammenfassung

Zwei nur einwöchige Grabungen wurden durchgeführt, um zusätzliche Informationen über die Stratigraphie der Fossil führenden Sedimente zu erlangen, aber auch um Proben für radiometrische Altersdatierungen zu entnehmen. Im ersten Jahr (1999) gelang diese im Bereich der „Bärengrotte", obwohl hier kaum noch ungestörte Sedimente anzutreffen sind. Bei der zweiten Aktion im Jahr 2001 konnten im Grabungsbereich „Kittls Bärenhöhle" fossilreiche Fundlagen mit mehreren Höhlenbärenschädeln ausgegraben werden. Das hier geborgene Schädel- und Gebiss-Material bildet die Grundlage für die neue paläontologische Bearbeitung der Ursidenreste.
Schlüsselwörter: Križna jama, Slowenien, Bechreibung der Nachgrabungen, 1999, 2001

Abstract

Two excavations with durations of one week each were carried out in Križna jama to obtain additional information on stratigraphy of the fossil-bearing sediments as well as to obtain material for radiometric dating. In 1999 this goal was achieved in the "Bärengrotte" despite the fact that there is almost no undisturbed sediment left. Later, in 2001, the excavation took place in "Kittl's Bärenhöhle" and fossil-bearing layers with several crania were found. The latter material consisted mainly of crania and other remains of dentition and forms the basis for the paleontological re-examination.
Keywords: Križna jama, Slovenia, description of reecavations, 1999, 2001

Izvleček

Dvoje enotedenskih izkopavanj v Križni jami je bilo namenjenih zbiranju novih podatkov o stratigrafiji sedimentov bogatih s fosili in izbiri materiala za radiometrično določevanje absolutne starosti. V letu 1999 smo zastavljeni cilj dosegli tudi v Medvedjem rovu, čeprav v njem skoraj ni več ohranjenih prvotnih sedimentov. Kasneje, leta 2001, smo izkopavali v Kittlovi dvorani in našli plasti bogate s fosili, še posebej z lobanjami. Ta material, ki sestoji v glavnem iz lobanj in zob je osnova novih paleontoloških raziskav, predstavljenih v tej publikaciji.
Ključne besede: Križna jama, Slovenija, 1999, 2001

1. Preamble

In 1996 a cooperation between the University of Ljubljana, the University of Vienna as well as of the Austrian Academy of Sciences was established, which lasted for several years. Its main aim was to re-examine the results obtained several decennials before by means of "more modern" methods with a special focus on radiometric dating of fossils and artifacts, as well as on the paleobiological re-examination of the fossil remains. The cooperation was aimed at an up-to-date analysis of the material left and an update of the knowledge of cave bears in Slovenia. After the successful excavations in Potočka zijalka in the years 1997 – 2000, see Pacher et al. (2004) a similar project was aimed at Križna jama.
It was Ferdinand von Hochstetter to be the first who carried out excavations in Križna jama in 1878 and 1879. His excavation areas were situated in two parts of

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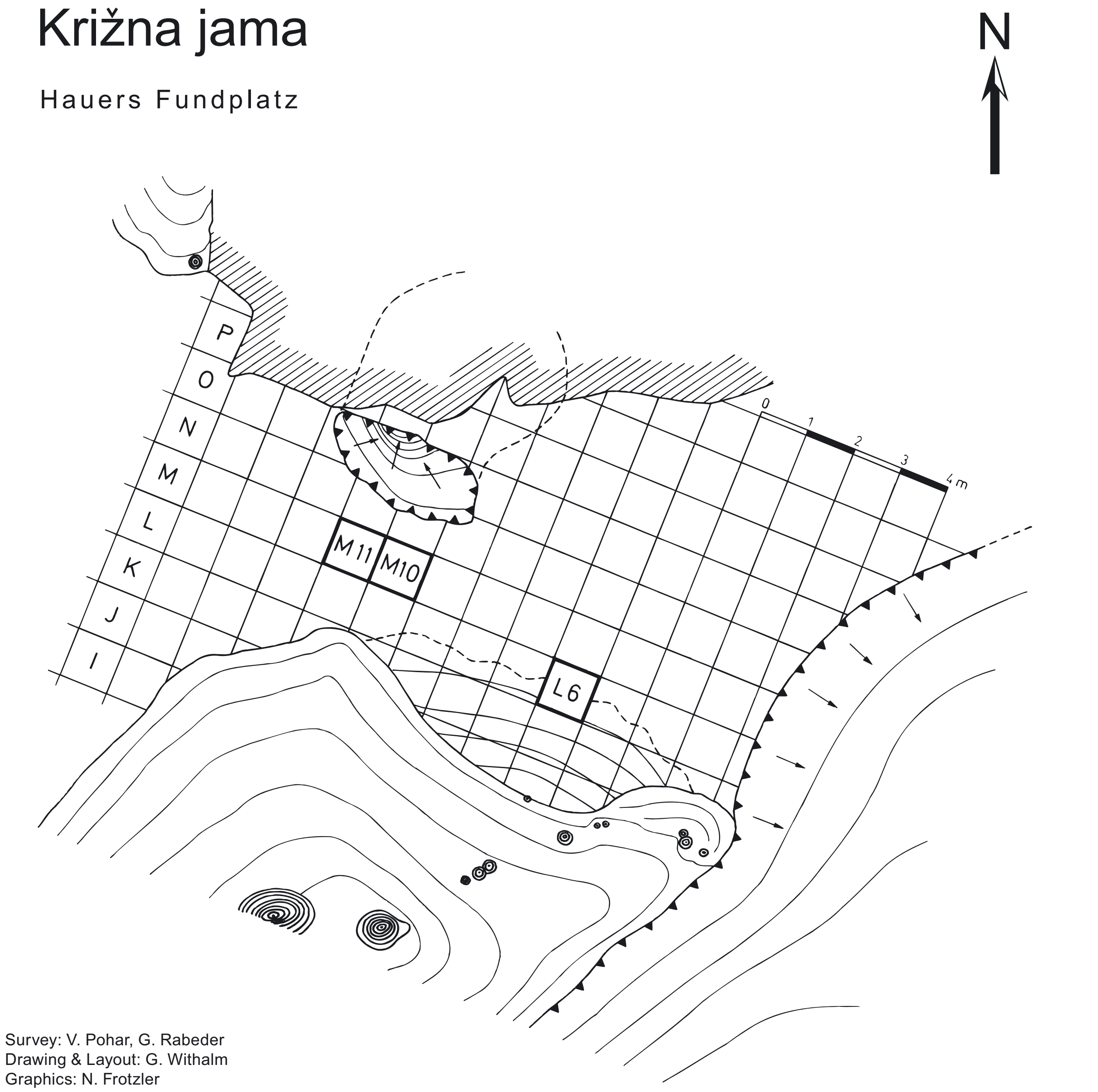

Figure 1: Schematic drawing of the excavation area (»Hauers Fundplatz«) near the »Monumentenhügel« (monument hill), compare to Pohar (this volume: 4, Fig. 3) and Plate 6.

the cave which were relatively far apart from each other, see Pohar (this volume: 4, Fig. 3): in the "Bärengrotte", a corridor branching off towards SW at the "See". It contains partly steep passages, leading us to "Hochstetters Schatzkammer", a big chamber filled with lots of flowstones, which is divided into two different excavation areas: "Bärenwirtshaus" and "Monumentenhügel". According to Hochstetter (1881) and the still visible traces, these old excavation areas are highlighted in Pohar (this volume: 4, Fig. 3). The second excavation area of Hochstetter was rich in fossils too. It is situated at the very end of the first chamber on the right side after the cave entrance, i.e. it branches off towards West. Due to the fact that it was mainly Erich Kittl who excavated in this place in 1879 this part is called "Kittl's Bärenhöhle".

In an excavation area of not more than 8 m^2 eight big skulls of cave bears were unearthed. As indicated before, the two excavation campaigns in 1999 and 2001 were aimed at a modern view on stratigraphy, to obtain sediment profiles and material for radiocarbon dating as well as for paleo-DNA-analyses.

2. The Re-Excavation in 1999

This excavation campaign took place from October 4^{th} – 8^{th} 1999 and was carried out under the direction of Prof. Dr. Vida Pohar (University of Ljubljana, Slovenia) and Prof. Dr. Gernot Rabeder (University of Vienna and Austrian Academy of Sciences, Austria).

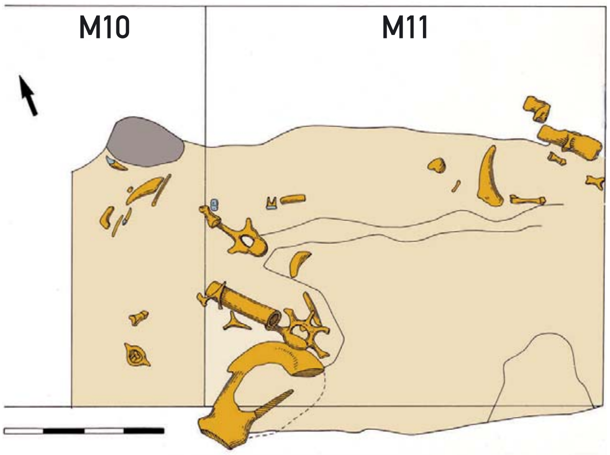

Figure 2: Finding situation near "Monumentenhügel" (monument hill).

Participants: Matej Križnar, Mladen Stefanovic, Mag. Margit Ströbitzer and Mag. Gerhard Withalm. This campaign took place in "Hochstetters Schatzkammer". In the area "Bärenwirtshaus" a profile was dug and a few fossil remains of cave bear were unearthed. This place was not rich in fossils.
The other area, "Monumentenhügel", was covered with an intact flowstone layer. Due to this fact excavation area 1 was established there, see Fig. 2. The overlying thin flowstone layer was removed in three square meters and the underlying fossils were unearthed. The squares M11 and M12 showed a layer of fossil remains of approximately 40 findings (bones, teeth and their fragments). Underneath this layer there were some more layers of flowstone and sterile loam. Due to this fact the excavation was ended. Bone samples were taken for the purpose of radiometric dating. Three of them showed ages between 44 and 45 ka BP, compare to Rabeder, Withalm & Wild, this volume.

3. The Re-Excavation in 2001

This campaign was carried out between October, 9th – 15th 2001 and was directed by Prof. Dr. Vida Pohar (University of Ljubljana, Slovenia) and Prof. Dr. Gernot Rabeder (University of Vienna and Austrian Academy of Sciences, Austria).
Participants: Eva Edelmann, Susanna Fitz, Miha Krofl, Johannes Loidl, Harald Pimminger, Agni Prijatelj, Dr. Karl Rauscher, Matija Turk, Mag. Gerhard Withalm.
The main focus of this excavation was to find fossil bearing sediments in the part called "Kittl's Bärenhöhle" which would have enabled us to carry out an excavation campaign in this part, which was named after Erich Kittl, an assistant to Ferdinand von Hochstetter. But in the time between 1999 and 2001 it became evident that the fossil material excavated in 1878 and 1879 was partly missing. The material is stored in the Museum of Natural History in Vienna and there still is a bigger number of postcranial elements, but there are no more crania and mandibles available, despite the fact that Hochstetter listed eight

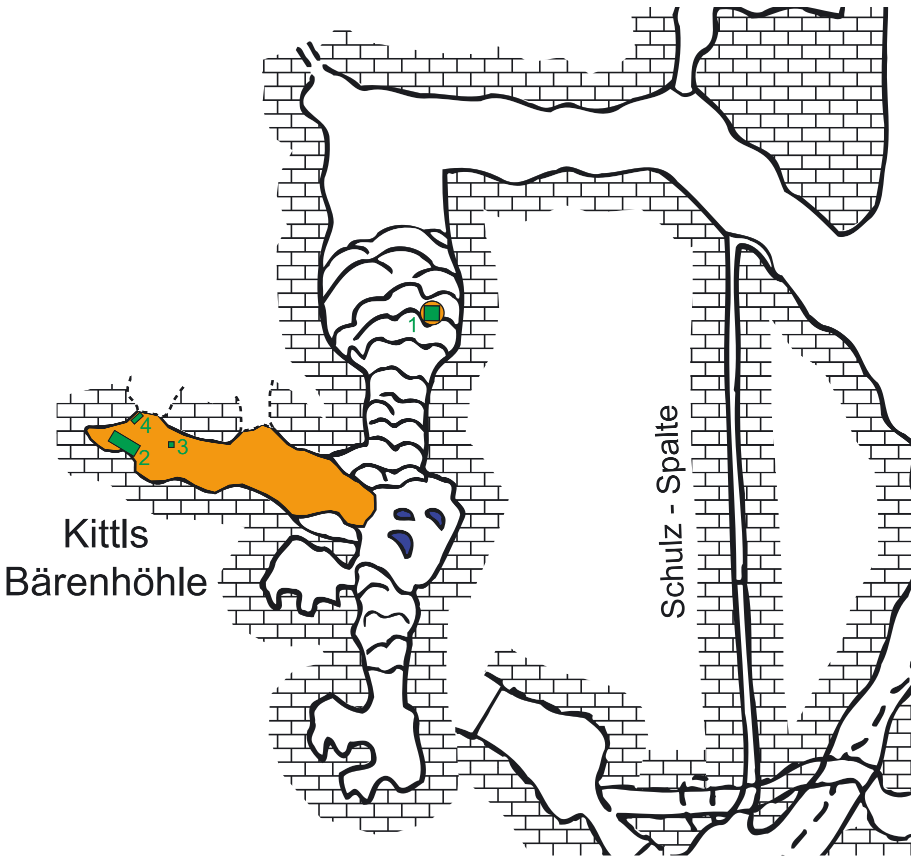

Figure 3: Enlarged detail of the ground map in Pohar, this volume: 4, Fig. 3. The area of »Kittl's Bärenhöhle« with a record of excavation areas 1 to 4, see also the upper part of Plate 4 and the lower ones of Plate 5 + 7.

Figure 4: Alignment of cave bear bones in square E4 (Kittl's Bärenhöhle, Križna jama, Slovenia).

Figure 5: Alignment of cave bear bones in square F5 (Kittl's Bärenhöhle, Križna jama, Slovenia).

Figure 6: Sedimentary profile at the border between squares H4 and I4 (Kittl's Bärenhöhle, Križna jama, Slovenia).

Figure 7: Deposition of skulls in excavation area 2:4 (Kittl's Bärenhöhle, Križna jama, Slovenia).

Figure 8: Layer full of skulls in excavation area 2:4

complete and 23 fragmented crania and not less than 90 mandibles. For a taxonomic re-examination of the cave bears from Križna jama a representative material of teeth and crania would have been necessary. Two out of four excavation areas in "Kittl's Bärenhöhle", no. 1 and 3, were not successful. Excavation area 1 showed a layer of loam with almost no fossils underneath a thick layer of moonmilk, in excavation area 3 the sediments were disturbed by former excavations. But in the western part of "Kittl's Bärenhöhle" there were undisturbed sediments which were rich in fossils. Excavation area 2 was installed and 7 m² were opened for excavation, see Fig. 4: excavation area 2. The fossil bearing layer is a dark-brown loam, containing little stones aside with high numbers of bone fragments, metapodial bones, autopodial elements and isolated teeth as well, compare to profile, Fig. 6. All in all more than 200 premolars and molars were unearthed. The position of the long bones leads to the conclusion that this sediment was transported by water, at least for a small distance. This is in accordance with the sedimentological results published by Kralj (this volume).

Close to excavation area 2 there is a shaft, which is partly filled with water. On its western margin there was place rich in fossils, preferably long bones and crania, which were hidden by blocks of stone and gravel. This is excavation area 4, see Fig. 7–8. In this place there were three big cave bear skulls, two of them were severely damaged on the dorsal side and it is very likely that these dam-ages are due to cavers because the skulls were covered only by a few centimeters of sediment. Moreover there were a mandible, a pelvis, several long bones and a few vertebrae. In excavation area 2 a profile was dug unto the solid rock of the cave floor, see Fig. 6. The fossil bearing layer is a greyish brown loam mixed with smaller stones and charcoal remains. Also Hochstetter saw these findings and wrote in his publication (Hochstetter, 1881:307) about the presence of "Holzkohle" (charcoal) and "verkohlten Körnern von Weizen" (burned grains of wheat). The latter were found in a flowstone layer which was missing in excavation area 2. The radiocarbon dating of this charcoal resulted in an age of 460 a BP, this equals calibrated age between 1210 an 1300 AD. This shows that flooding events and transport by water are phenomena that influence the highest part of the Križna jama even in historic times. The fossil bearing layer itself has a thickness between 40 and 50 cm with and underlying layer of sterile loam of similar thickness. Its brown colour becomes lighter and lighter with increasing depth. The whole sediment pile is stacked on a more or less horizontal floor of solid rock. Both re-excavations enabled us to find answers for the most essential questions on the situation of findings, stratigraphy and chronology as well. Moreover, the excavation in "Kittl's Bärenhöhle" brought a multitude of newly unearthed material of teeth and crania, giving us the possibility to resolve the taxonomic position of the cave bear from Križna jama.

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Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:15 – 20, Wien 2014

The Geological Setting of Križna jama

by

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Knez, M. & Prelovšek, M., 2014. The Geological Setting of Križna jama. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:15 – 20, Wien.

Zusammenfassung

Geologisch gesehen liegt die Križna jama in einer Synklinale zwischen dem Bloke-Plateau und der Idrija-Störungszone. Die ältesten Gesteine in dieser Synklinale sind aus der Oberen Trias, die jüngsten stammen aus dem Oberen Jura. Dazwischen liegen Serien von Kalken, die entweder geschichtet sind, Linsen und Dolomitnester aufweisen. Die Gesteine in der Synklinale sind nur wenig gestört, doch zeichnen lokale Störungen gemeinsam mit tektonisierten Schichtflächen für die Entstehung einiger Passagen der Križna jama verantwortlich. Letztere liegen vor allem in Kalken des Unteren- bis Mittleren Jura, wohingegen nur die Passagen am äußersten nordwestlichen Ende in der Kontaktzone mit oder aber bereits in Dolomiten des Unteren Jura liegen. Die Speläogenese der Križna jama ist auch abhängig von den obertriassischen Dolomiten, da diese das Oberflächenwasser des Bloke-Plateaus ableiten und dadurch die Hydrologie sowie die allochthonen Sedimente in der Križna jama beeinflussen.
Schlüsselwörter: Križna jama, Geologie, Kalke, Slowenien

Summary

From the geological point of view, Križna jama is located in a syncline between the Bloke plateau and the Idrija fault zone. The oldest rocks in this syncline are Upper Triassic dolomites, while the youngest are Upper Jurassic limestones. Between them are series of limestones with strata, lenses or nests of dolomites. The syncline shows relatively weak faulting but local faults, together with tectonized bedding planes, can guide the formation of some Križna jama passages. The latter are mainly located in Lower-Middle Jurassic limestones, while only the passages at the furthest north-eastern end are located at the contact with (or already in) Lower Jurassic dolomite. The speleogenesis of Križna jama also depends on Upper Triassic dolomite since this drains surface water on the Bloke plateau and affects the hydrology of Križna jama and allochthonous sediments in it.
Keywords: Križna jama, geology, limestone, Slovenia

Izvleček

Križna jama je geološko gledano umeščena v sinklinalo med Bloško planoto in Idrijsko prelomno cono. V sinklinali so najstarejše kamnine zgornje triasni dolomiti, najmlajše pa zgornje jurski apnenci. Med njima se nahaja serija apnencev, v katerih se mestoma pojavljajo plasti, leče ali grozdi dolomita. Blok je tektonsko relativno slabo razlomljen, čeprav lahko lokalni prelomi skupaj s tektoniziranimi lezikami lokalno vplivajo na potek podzemnih rovov Križne jame. Slednji ležijo večinoma v spodnje in srednje jurskem apnencu, le skrajni severovzhodni deli se dotikajo oz, že ležijo v spodnje jurskem dolomitu. Na oblikovanje Križne jame vplivajo tudi zgornje triasni dolomiti na Bloški planoti, saj s površinskim zbiranjem vode vplivajo na hidrološke značilnosti Križne jame ter pojav alohtonih sedimentov v njej.
Ključne besede: Križna jama, geologija, apnenec, Slovenija

1. Previous Investigations

The first geological observation of the entrance part of Križna jama (up to the first lake) is closely related with palaeontological research in the cave. Therefore it was done by Austrian geologist Ferdinand von Hochstetter in 1881, who digged out more than 2,000 bones of cave bears at the end of 19th century. Milovanovič (1937, ex

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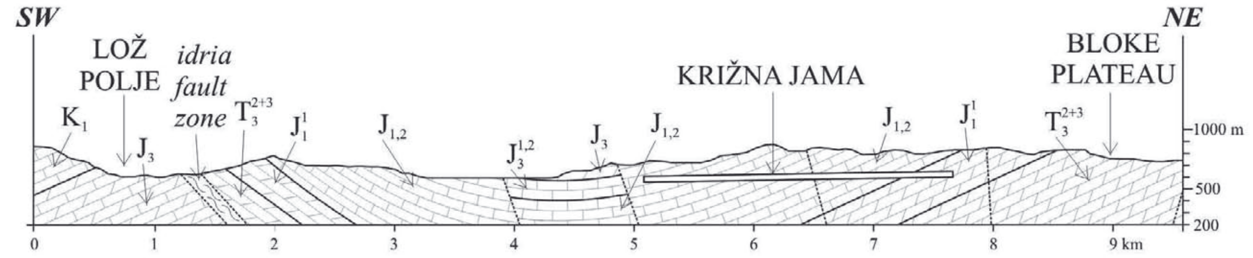

Figure 1: Schematic geological cross-section perpendicular to the syncline's axis (Bloke plateau-Lož polje) with position of Križna jama (modified after Gospodarič, 1974).

Pleničar, 1953) investigated liasic limestones in the SE periphery of Cerknica polje that is wider area of Križna jama. In 50-ies the wider area of Cerknica polje was investigated by geologist Pleničar (1953). The main purpose of his work was to define geological structure of Cerknica polje. About 62 boreholes were drilled at that time in the bottom of Cerknica polje and also some lithological and tectonical studies were done by Pleničar (1953). And finally, wider area around Križna jama was mapped and described in the framework of Yugoslav Elementary geological map, which was done for this area between 1959 and 1963. The geological settings are presented on the geological maps Ribnica and Postojna in the scale 1:100,000 and in the Commentary of Elementary geological maps (Buser, 1965; Pleničar et al., 1970). Later on the area between Bloke plateau, Cerknica and Lož polje was studied by Gospodarič (1974) from geological and karstological point of view. He made some significant conclusions on stratigraphical, sedimentological and tectonical conditions of this area. Geological observation of inner parts of Križna jama was primary done by first cavers (semi-speleologists; Planina, 1965; Puc, 1986), in 70-ies by Gospodarič (1974) and later by Prelovšek (2006).

2. Litostratigraphy

The carbonate block between Bloke plateau, Cerknica and Lož polje is composed of relatively simple sequence of carbonate rocks of Upper Triassic to Upper Jurassic age. Generally, strata are not much moved in horizontal or vertical direction but they are significantly bended in so called Dinaric (SE-NW) direction. This bending produces a simple syncline (Fig 1). On the surface syncline is recognized by a sequence of carbonate rock that grows progressively younger toward the axis of syncline. The youngest rocks are therefore found at the fold's axis and the oldest more than 2.5 km from the syncline axis. Entrance of Križna jama lies only 1 km NE from the syncline's axis, therefore the strata dip in Križna jama is about 25 degrees toward SW (Gospodarič, 1974). In the longitudinal section (NW-SE) syncline is beginning near Cerknica and continues through Križna jama toward syncline of Racna gore. On Racna gora the axis of syncline is composed of even younger, Lower Cretaceous carbonates. Southern and western part of Bloke plateau is completely composed of Upper Triassic rocks. This very thick layer of light grey dolomite is due to low hydraulic gradient and tectonic deformations non permeable for water. Two main brooks appear at Bloke plateau, which are important for the aquifer around Križna jama – Bloščica and Farovščica. Because of thickness and tectonic movements, complete thickness of Upper Triassic dolomite is difficult to measure – it is just estimated from 750 to 1,500 m (Buser, 1965; Pleničar et al., 1970). Its low resistance to physical weathering produces usually parallelepipedic gravel (Pleničar, 1953) which completely covers compact base layers of dolomite and produces thicker soils in comparison with limestones. On steeper slopes dolomitic soils creep to hill's foot and produces well-expressed colluviums. Such colluviums can be easily noticed at Bloke plateau and below Slivnica mountain. High rates of physical weathering results in low-energy and quite leveled Bloke plateau. In Upper Triassic dolomites caves are quite rare; usually they develop as ponors where dolomites are fractured but not tectonically crushed. Higher degree of tectonic crushed Upper Triassic dolomites can be found on the SW side of syncline near the Idria fault zone where it acts as hydrological barrier. Fossils due to secondary dolomitization are absent (Pleničar, 1953).

Lower Jurassic dolomite unconformably lies on Upper Triassic dolomites. Due to syncline structure dolomites are exposed on the surface as two stripes: northeastern and southwestern. On northeastern stripe are placed settlements Bločice, Bloška Polica and part of the settlement Grahovo and on the southwestern Goričice, Podcerkev and part of the settlement Stari trg pri Ložu. From the viewpoint of physical weathering, Lower Jurassic dolomites are similar to Upper Triassic dolomites. Therefore, outcrops of this light grey and bituminous dolomite on the surface are quite rare. Because of its composition (cemented fine-grained particles), incomplete solution produces fine-gained sand, which is incorporated in the soil matrix. In the majority of sequence fossils are rare while in some less dolomitized sequence we can found many shells of *Lithios problematica* (Pleničar et al., 1970). Fossil-bearing strata usually contain few millimeters thick layers of clay within bedding planes. Thickness of Lower Jurassic dolomites is estimated from 140 to 410 m (Buser, 1965; Pleničar et al., 1970). Since they lie closer to the syncline's axis, 420 m of the

Figure 2: Dolomite nest (in black) in Lower-Middle Jurassic limestones as can be seen in water passage of Križna jama 2. In Križna jama dolomite nests are rarer.

upper part of Blata passage in Križna jama are developed in this dolomite (Prelovšek, 2006) and probably northern ending passage of Pisani rov (Gospodarič, 1974). In the Blata passage the transition between Lower-Middle Jurassic limestone and Lower Jurassic dolomite is clearly visible – limestone can be seen all the way from Kalvarija to the place 300 m northern from the Mišnica, where SW dipping limestone strata are replaced by dolomite strata dipping in the same direction. Transition occurs in few meters. It is interesting that morphology of the Blata passage is not much changed at transition, only microforms on the cave walls disappears because of dolomite's fine-grained structure. We can observe also gradual narrowing of passage from 20 m in limestone to around 10 m in dolomite.
The most important strata for Križna jama are Lower-Middle Jurassic limestones, where all the passages (except 420 m of Blata passage and few tens of meters of Pisani rov) are developed. Thickness of strata is estimated from 500 to 750 m (Pleničar et al., 1970). Since the strata dip of Lower-Middle Jurassic limestones is not larger than 25 degrees, 7,800 m long Križna jama's horizontal passages could develop in not more than 750 m thick strata. According to Folk's classification these limestone is classified as micrite and oomicrite. Since the limestone sequence was secondary dolomitized, dolomite layers, lenses and nests can be found within Lower-Middle Jurassic limestone. In the Middle Jurassic rocks they can completely prevail. In Križna jama Lower-Middle Jurassic dolomite is nicely visible as wall jag due to its slower dissolution rates. In Križna jama 2 they are easily recognized since they are usually covered with black (manganese or organic?) coating (Fig. 2).
Upper Jurassic carbonates lies in the axis of syncline southwestern from Križna jama. Since they are represented as dolomites and Štebrščica spring lies on the contact between Lower-Middle Jurassic limestone and Upper Jurassic dolomites we prefer those dolomites as less permeable for underground water flow. Due to lower secondary porosity they influence the piezometric water level in the hinterland and indirectly influence also on the water levels in Križna jama and Križna jama 2.
In the area between Bloke plateau, Cerknica and Lož polje Cretaceous strata are not preserved and were probably eroded by dissolution in the past. The nearest outcrops are located 5 km SE from Križna jama and do not have any influence to Križna jama.
The youngest sediments of Pleistocene and Holocene age cover karst poljes (Cerknica and Lož polje) and other closed depressions (Bloke plateau and Bločice "uvala"). In Pleistocene were deposited also the sediments which are

Figure 3: Allochthonous sediment on the corrosion shelf deposited between 1st and 2nd lake in Križna jama.

Figure 4: Collapsed zone above 2nd lake in Križna jama.

found in Križna jama as cave fillings (Gospodarič, 1974). According to its lithological composition (Upper Triassic dolomite, Lower Jurassic dolomite, chert, oolithic bauxite, and Lower-Middle Jurassic limestone; Gospodarič, 1974) their provenance is nearby Križna jama and in the northern part of Bloke plateau. They were deposited almost in the all passages in Križna jama up to 5 m above present-day water level. The best preserved sediments of this type are found at Križna gora and Kalvarija, where the erosion was very limited due to more than 10 m wide passages. In other parts of a cave they are presented as erosional remnants (Fig. 3). The same sediments are found also downward from Križna jama – in Križna jama 2. Present-day stream in Križna jama transports and deposits just fine sand, silt and clay. Almost all along Pisani rov, Blata passage and Jezerski/Glavni rov sinter is deposited in channel in the form of flowstone and rimstone dams.

3. Tectonic Settings

Initial development of passages is strongly related to ductile deformation of carbonate strata. Development of passages is based on rock solubility, water aggressiveness, hydraulic gradient and interconnected network of cracks. Amongst them we can place also tectonized bedding planes since bedding planes as such are impermeable for water. They become permeable after tectonic displacement which opens the bedding plane so much, that enables the water flow along it. Therefore tectonic action is necessary for cave development.

Carbonate rocks behave differently on tectonic stress as some other sedimentary, methamorphic or magmatic rocks. Therefore Čar (1981) distinguishes between three different tectonic zones regarding to degree of fracturization: fissured zone, collapsed zone and crushed/milonite zone. The most suitable zone for underground passage development is the first one since it enables the water flow and still supports the stability of passage roof. Collapsed zone is suitable for water flow but when the passage grows, the stability of roof is reduced. The passage can be preserved only if the collapsed blocks are constantly removed by erosion or corrosion. Crushed and milonite zone are usually unsuitable for passage development since the rocks are completely crushed in tectonic clay, milonite and breccia and usually additionally clayed by turbid water flow (Čar, 1981). Usually, such zone acts as hydrogeological barrier and directs water flow to the surface or along zone. Such a case is the central part of Idria fault, where the majority of movement occurred. Drilling into the

Figure 5: Cross section of main water passage near Ponor with well expressed bedding planes. Along bedding planes the channel was formed.

bottom of Cerknica polje showed many crushed rocks (Pleničar, 1953). Despite the observation of slight water flow through the bottom of Cerknica polje (Pleničar, 1953), crushed rocks are usually impermeable for water and this is the main cause for polje formation. Since the crushed zones are bounded with much more permeable collapsed and fissured, they are permeable for corrosive water and this enables underground flow parallelly with or perpendicularly to poljes. In such a tectonic zone lies majority of Križna jama passages. If the collapsed zones were not cemented with calcite, usually breakdowns are extensive and numerous.

Although Križna jama lies several kilometers from Idria fault zone carbonate massive between Bloke plateau and Cerknica polje did not suffer any important tectonic movement. Therefore syncline is very well preserved in the area of Križna jama. Major movement occurred 4 km southwestern from Križna jama, where syncline is cut and we have tectonic junction of Upper Triassic dolomite and Upper Jurassic limestone with very different dipping. Although, there are some minor tectonic movement nearby Križna jama, for example as fault-junction of Upper Jurassic dolomites border Middle Jurassic limestones in the axis of syncline (Gospodarič, 1974). Relatively slight tectonic movements are observed also in Križna jama. Majority of these strike-slip faults have N-S direction and are initiative features for many passages, i.e. passage Ponor, passage between 3rd and 5th lake, passage between Goba and Otok. Less common but not less important are faults in northwest-southeast and northeast-southwest direction where some big collapse chambers are formed (Cerarjeva dvorana, northwestern part of Suhi rov, Križna and Kristalna gora, collapse chambers in Blata passage). At some places tectonic deformation at collapsed zone was not so intensive and the rock still supports the roof without significant breakdown (Fig. 4). Particularly important are movements along bedding planes which have strong influence on water permeability. Since they are dipping toward southwest, they prefer water movements generally in E-W direction. Such relation between dipping of strata and water movement can be seen at Glavni/Jezerski rov by the Ponor (Fig. 5), at the lower part of Pisani rov and at the lower part of Blata passage.

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Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:21 – 26, Wien 2014

Speleogenesis and Flowstone Deposition in Križna jama

by

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Prelovšek, M., 2014. Speleogenesis and Flowstone Deposition in Križna jama. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:21 – 26, Wien.

Zusammenfassung

Die Speläogenese der Križna jama ist einerseits charakterisiert durch eine Serie von allochthonen und autochthonen Materialablagerungen, und andrerseits durch mechanische und chemische Erosion dieser Sedimente. Aufgrund der Morphologie der Passagen und anhand von Typ und Ort der Sedimentation können sechs speläogenetische 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, Speläogenese, 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 mechanical 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 rovov v obliki mehanske in kemične erozije. Na podlagi morfologije rovov, tipa in lokacije sedimentov lahko izpostavimo 6 speleogenetskih faz (5 sedimentacijskih in 1 erozijska).V predfazi je prišlo do oblikovanja glavnih rovov, ki so bili v 1. fazi deloma zapolnjeni s pretežno elohtonimi prodnatimi in peščenimi nanosi.V 2. fazi se je ta prod deloma cementiral s sigo iz prenikle vode. Tretja faza je obdobje odlaganja finozrnatih sediementov. 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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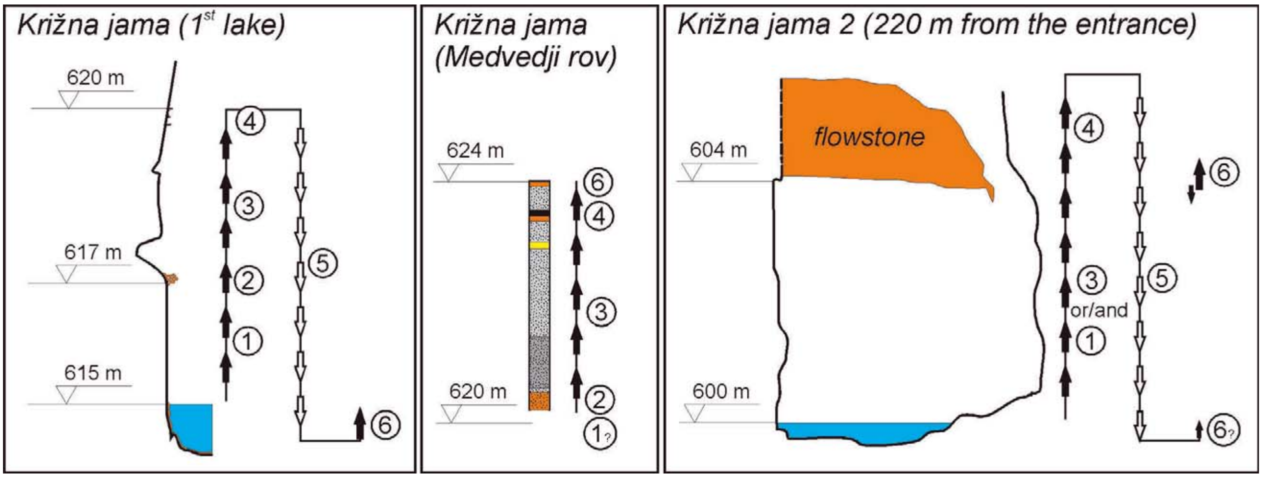

Figure 1: Sequence of sediment and most evident events in Križna jam and Križna jama 2.

(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 (Atkinson 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 Wurmian 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. Therefore it is necessary to deal with the whole speleogenesis instead of limited study of chronologically dated flowstones. According to detailed study of allochtonous 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 allochtonous 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.

drologically 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 allochtonous 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. Allochtonous 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 climatalogical 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 ^{14}C 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 entrenced 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 CO_2 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.

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The Hydrogeological Setting of Križna jama

by

Mitja Prelovšek [1)]

Prelovšek, M., 2014. The Hydrogeological Setting of Križna jama. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:27–33, Wien.

Zusammenfassung

Aus hydrogeologischer Sicht liegt die Križna jama in einem dreieckigen Aquifer, der aus dem Bloke-Plateau, Cerknica Polje und dem Lož Polje besteht. Während Niedrigwasser-Phasen wird die Križna jama v.a. durch Sickerwässer aus dem naheliegenden hügeligen Karstgebiet versorgt. Bei Hochwasser wird die Križna jama auch mit allogenetischem Wasser des Bloke-Plateaus versorgt. Dieses Wasser erscheint dann wieder flußabwärts in der Križna jama 2 und schließlich in der Štebrščica-Quelle am Rand des Zirknitzer-Sees. Die Verbindungen der unterirdischen Wasserwege wurden durch eine Serie von Tracer-Versuchen nachgewiesen. Aufgrund der überwiegend autogenischen Grundwasseranreicherung ist das Wasser reich an CO_2 und gelöstem Calcit und Dolomit, was Sinterbildung ermöglicht. Die Wassertemperatur ist stabil, genauso wie die Durchflussmenge. Im Sommer kann der Durchfluss beim ersten See versiegen und bei Hochwasserständen bis zu mehreren Kubikmeter pro Sekunde ansteigen. Der mittlere Durchfluss in der Križna jama liegt bei 0,2 m^3/s. Während des Pleistozäns war der Wassereintrag aus dem Bloke-Plateau viel größer, was dazu geführt hat, dass es keine Sinterbildung gegeben hat.
Schlüsselwörter: Križna jama, Hydrogeologie, Karst-Aquifer, Tracer-Versuche, lokale Versorgung, Slowenien

Abstract

From the hydrogeological point of view, Križna jama is located in the aquifer in the triangle formed by the Bloke plateau, Cerknica polje and Lož polje. During periods of low water levels, Križna jama is mainly characterized by the flow of percolated water from the nearby hilly karst area. When water levels are high, Križna jama also drains allogenic water from the Bloke plateau. The water reappears downstream in Križna jama 2 and, finally, in the Štebrščica spring at the edge of Cerknica polje. Underground water connections have been proved by a series of tracer tests. Owing to the mainly autogenic recharge, the water is rich in CO_2, dissolved calcite and dolomite, and therefore flowstone is deposited from the water. Water temperature is stable, as is general discharge. Water flow can, however, dry up during summer near the first lake and can increase by several cubic metres per second during flood events. Average discharge through the cave is approximately 0.2 m^3/s. Water flow from the Bloke Plateau was probably much more intense during the Pleistocene, as a result of which flowstone was not deposited from the water.
Key words: Križna jama, hydrogeology, karst aquifer, water tracing, autogenic recharge, Slovenia

Izvleček

Hidrogeološko gledano leži Križna jama v vodonosniku med Bloško planoto, Loškim in Cerkniškim poljem. Ob nizkem vodostaju se skozi njo pretaka večinoma prenikla voda iz okoliškega kraškega hribovja, ob visokem pa tudi ponorna voda z Bloške planote. Voda iz Križne jame se dolvodno pojavi tudi v Križni jami 2, na površju pa v izviru Štebrščice ob robu Cerkniškega polja. To je bilo potrjeno z nizom sledilnih poskusov. Zaradi pretežno avtogenega napajanja so vode bogate s CO_2 ter raztopljenim kalcitom in dolomitom, zato se iz nje odlaga siga. Voda ima tudi konstantno temperaturo in dokaj konstanten pretok. Kljub temu lahko leta v poletnem času okoli 1. jezera povsem presahne, ob padavinah pa naraste na več m^3/s. Povprečen pretok znaša okoli 0,2 m^3/s. V pleistocenu je bil dotok z Bloške planote najverjetneje precej intenzivnejši iz vode pa se siga ni odlagala.
Ključne besede: Križna jama, hidrogeologija, kraški vodonosnik, sledenje, avtogeno napajanje, Slovenija

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1. Introduction

Križna jama belongs to the aquifer between Bloke plateau, Cerknica polje and Lož polje. Due to underground hydraulic gradient from NE (Bloke plateau) toward SW (Cerknica and Lož polje) general water flow is oriented in this direction. This is also a direction of water flow in Križna jama. From this point of view, the general hydrological situation seems to be clear – waters that flow superficially on Bloke plateau sink there, reappear in Križna jama and Križna jama 2 and appear at the surface again at Cerknica polje. Such thinking prevailed from the earliest explorations but recently done studies (Kogovšek et al., 2008; Prelovšek, unpublished) raised a big question on validity of such thinking. Probably the biggest mistake done in the past was neglecting of autogenic recharge of aquifer which can contribute about 66% of water to the aquifer. Where does this water flow? Can we neglect many tributaries in Križna jama and their variable hydrological function during low and high water levels? What is the function of dolomite in the upstream parts of aquifer and in Križna jama?

Now we know that basic hydrogeological situation is in general very simple but in details quite complex and therefore complicated. Simple structure of two brooks that disappear at Bloke plateau, reappear in Pisani rov and Blata passage, join at Kalvarija and appear at Cerknica polje is much more complicated. Some basic hydrological functions of Križna jama are already known now, but some detailed work is still needed to confirm elementary ideas.

2. Hydrological Settings of Križna jama's Surrounding

From the hydrogeological point of view Križna jama lies between fluvio-karstic Bloke plateau on the NE and mainly karstic Cerknica basin on the SW (Fig. 1). Between Bloke plateau and Cerknica polje spreads out completely karstified surface without superficial streams. Consequently, due to combined underground water flow of originally superficial water and waters, which percolate through vadose zone, aquifer around Križna jama is composed of allogenic and autogenic recharge (Fig. 3).

Only two major brooks on Bloke plateau contribute allogenic water to the aquifer between Bloke plateau, Cerknica and Lož polje: Bloščica and Farovščica. Both are fed by minor karst springs and partially by surface runoff. Catchment area of Bloščica brook extends on

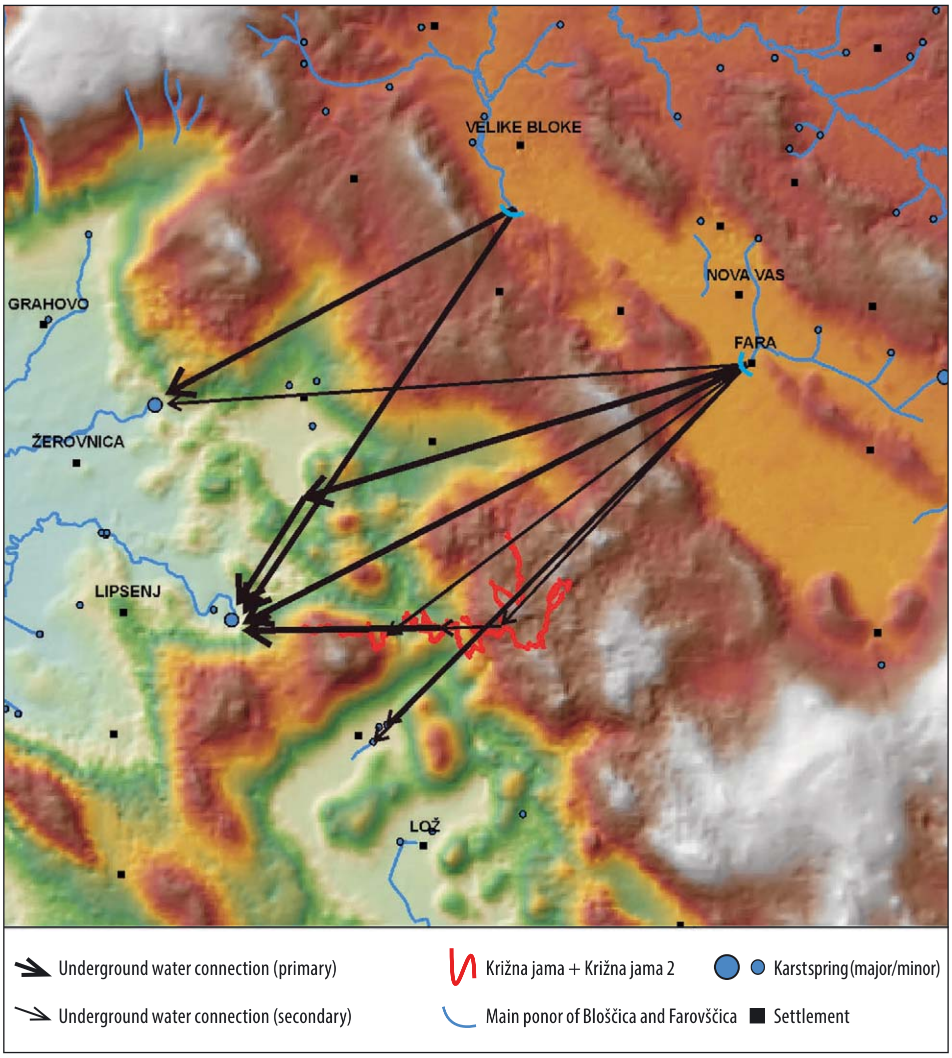

Figure 1: Proved groundwater connections between Bloke plateau, Cernica and Lož polje (water connections after Novak, 1990; Kogovšek et al., 2008; DEM after IAPŠ ZRC SAZU, 2005).

19.5 km^2 and Farovščica on only 4 km^2. Between 1972 and 1975 mean discharge of Bloščica was 0.42 m^3/s, maximum discharge was 15.9 m^3/s and minimum discharge 0.02 m^3/s (Gospodarič & Habič, 1976:49). Discharge of Farovščica is much smaller; according to Bloščica drainage area characteristics, mean discharge of Farovščica should be 0.085 m^3/s. This fits quite well with field observation. According to dye tracing experiments (Novak, 1966, 1969, 1990; Kogovšek et al., 2007) Bloščica and Farovščica appear once again on the surface at the springs Štebrščica and Žerovniščica (western part of Cerknica polje). Between 1972 and 1975 mean discharge of Štebrščica was 1.3 m^3/s, maximum discharge 16.0 m^3/s and minimum discharge 0.01 m^3/s. In the same years, mean discharge of Žerovniščica was 0.21 m^3/s, maximum discharge 7.59 m^3/s and minimum discharge 0.01 m^3/s. Comparison between superficial inputs of the aquifer (Bloščica and Farovščica) and outputs of the aquifer (Štebrščica and Žerovniščica) indicates that 34% of water derives from superficial input. The rest (66% of water) originates in the vadose zone and feed the aquifer as autogenic water (Fig. 1).

Ancient belief connected with hydrology of Križna jama was that the brooks in Križna jama are the continuation of Bloščica and Farovščica stream in the underground. Water in the Pirani rov passage should be "underground Farovščica" and water in the Blata should be at least partly from the "underground Bloščica". This anticipation was not built on dye tracing experiments but on discharge observation (especially when the floods on Bloke plateau appears), polystyrene findings in Pisani rov and Glavni/Jezerski rov (the polystyrene was deposited in the high-water Farovščica's ponors) and allogenic sediments in Križna cave (the provenance of this sediments lies in the northern Bloke plateau). It is interesting that the idea of a continuation of Bloščica's and Farovščica's underground flow in Križna jama was easily accepted by early cavers, that explored the Križna jama (Puc, 1986), and also by karstologists (for example Gospodarič, 1974). If we do not take into account high degree of autogenic recharge and physical characteristics of water in Križna jama, the idea of continued superficial and underground flow seems to be quite persuasive.

Contrary to the ideas of Farovščica and Bloščica underground flow in Križna jama are physical and chemical observations of water in Križna jama. Mean water temperature in Križna jama (1st lake) is usually about 8.1° C and the annual fluctuation in water temperature rarely exceed 1° C. At 1st lake positive deviation from the mean temperature was observed in the beginning of flood pulse in summer, which is connected with flow through vadose zone. Lower water temperature is characteristic for winter time, when the cold are that is entering the cave cool down the water in the 1st lake. In any case variations in water temperatures are very small and can not be related to Bloščica and Farovščica where the annual fluctuations over 20° C can be observed. It is practically impossible that even at high water level surface waters would adapt cave's temperature within 2.3 km of underground flow. On the contrary, the highest change in annual water

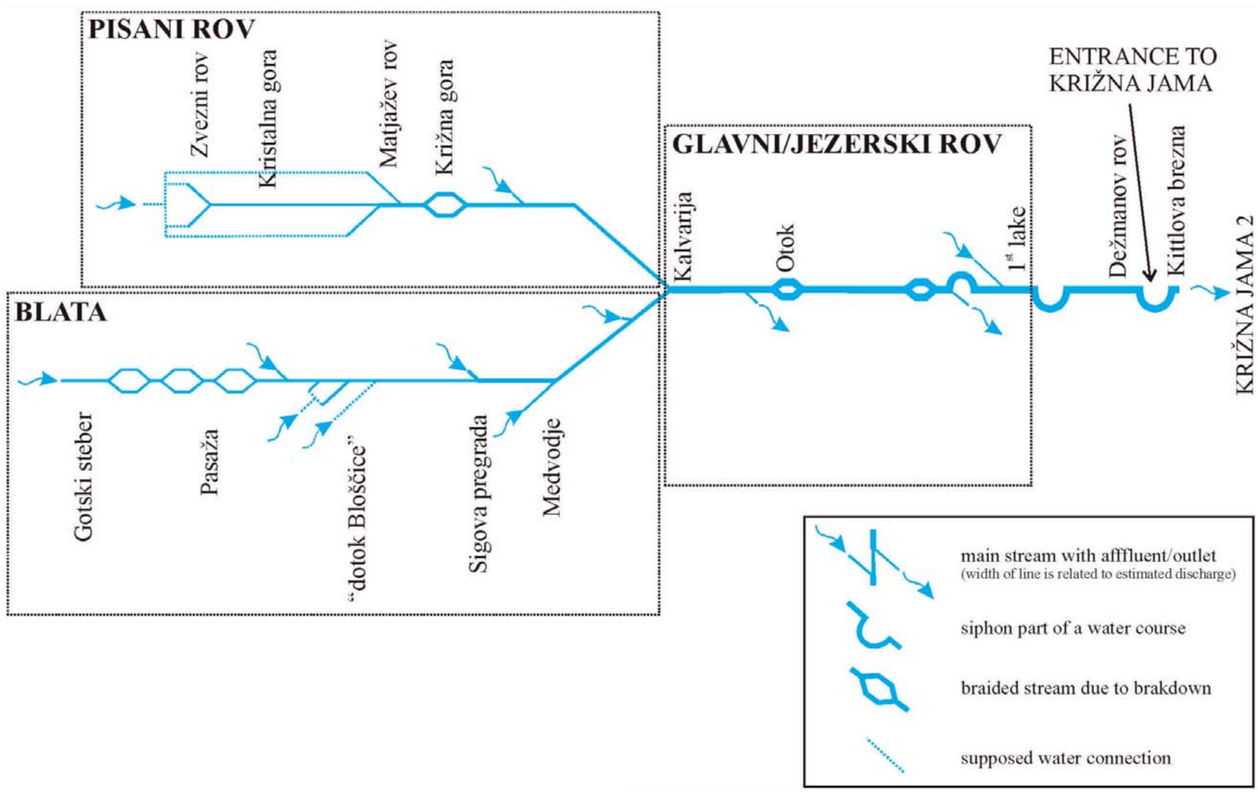

Figure 2: Scheme of hydrological network in Križna jama during low and middle water level. Note that the cave is a collector of autogenic water since it has many inflows and rare outflows.

temperature was observed in Mrzla jama pri Bločicah, where the underground continuation of Farovščica was proved with dye tracing experiment (Kogovšek et al., 2007; Kogovšek et al., 2008). There the annual water temperature variations exceed 4° C. In the past, this northern underground water flow was proposed already by Novak (1966) but till 2007 (Kogovšek et al., 2007) never proved by tracing test. In Križna jama we can observe also a strong influence of surface vegetation, which intercept and evapotranspirate a lot of precipitation in summer time (fast decline of discharge after the precipitation) and much less in winter time (slow decline of discharge after the precipitation; Troha, 2005).

Questionableness of water connection between Farovščica and Križna jama was confirmed by dye tracing experiment at middle water level from the Farovščica ponor – among 88% of recovered tracer we detected only 1.3% of tracer in Križna jama (Kogovšek et al., 2008), Fig. 1. First of all the dye appeared in Mrzla jama pri Bločicah, then in Križna jama 2 (which is lying downward of Križna jama) and only then at 1st lake in Križna jama. This proved that waters of Farovščica flow northern from Križna jama and partly join Križna jama – Križna jama 2 water course between caves. Since the waters of Bloščica most likely flow northern from Farovščica-Štebrščica underground water flow, Križna jama seems to be fed by autogenic recharge from the surrounding of passages. In spite of this findings of polystyrene (Troha, 2005) and occasional occurrence of polluted waters (foams) doubtlessly prove, that at high water level catchment area of Križna jama extends also on the catchment area of Farovščica (Fig. 3).

Downstream from Križna jama water flow was never questionable. In 1965 Novak (1966, 1969, 1990) proved by means of dye tracing experiments the connection between Ponor, Dežmanov rov, northern sump of Kittlova brezna and Štebrščica passage. At middle water level average flow velocity was 0.9 cm/s (Novak, 1990). Between northern sump of Kittlovo brezno and Štebrščica spring water very likely flows through Križna jama 2. This connection seems to be logical due to suitable hydraulic gradient, distance (240 m), similar physical and chemical characteristics of water (Prelovšek, 2006), similar composition of allogenic sediments, *Ursus spelaeus* bones and charcoal findings in Križna jama 2.

3. The Hydrological Network in Križna jama

Brooks from Pisani rov and Blata passage and its uniform watercourse from Kalvarija through Jezerski/Glavni rov, Dežmanov rov and northern sump of Kittlova brezna represent the skeleton of hydrological network in Križna jama (Fig. 2). Both brooks appear under the breakdowns beyond which probably some unknown passages exist. At the upstream end of Pisani rov, brook is dammed with two breakdowns (Kristalna gora and breakdown at the end of Matjažev rov). These breakdowns probably divide uniform water flow into the four chemically very similar springs under the breakdowns. 450 m downward from Križna gora a left tributary joins the major brook in Pisani rov. At lower-middle water level contribute about 16% of water into the Pisani rov water course. Dissimilarity of this tributary according to SEC, pH and T proves different catchment area in comparison with main water course in Pisani rov. In spite of all that, the hydrologic network in Pisani rov seems to be quite simple.

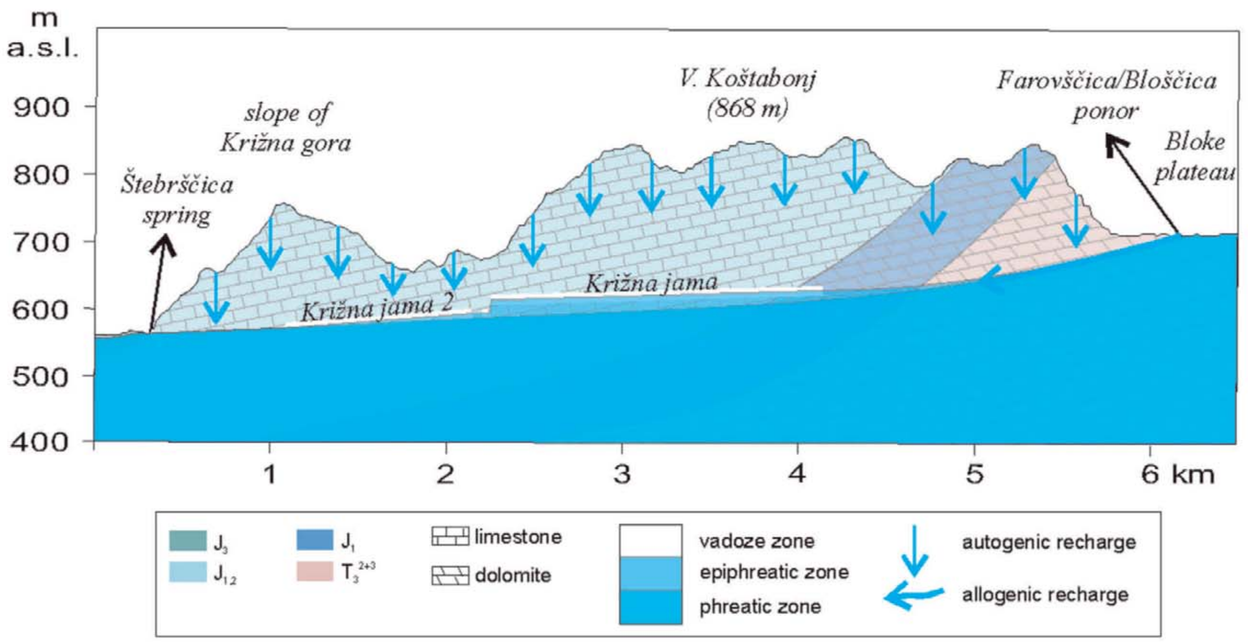

Figure 3: Underground flow of allogenic water from Bloke plateau to Cerknica polje. Note that Križna jama is generally fed by autogenic water since it is slightly above the flow of allogenic water.

Hydrological situation in Blata passage is more complex since the major water course gets at least six tributaries. The main, but not always the strongest spring in Blata passage originates under the ending breakdown. Some 200 m downward, this brook with discharge of several liters per second gets left tributary from the dolomite. At low-middle water level its portion is about 25%. According to morphological observation main stream and dolomite tributary does not contribute much water even at high water level. Few tens of meters downward from dolomite tributary usually not more than 1% of water in Blata passage flows from two right springs, which are due to similar chemical characteristics connected in the hinterland. Besides them lie more than 3 m wide and more than 20 m long side passage which terminates in the sump. At middle water level it does not contribute any water, but according to wash out breakdown at the junction with main stream and dimension of passages discharge can reach several m^3/s at high water level. Since it lies in the direction of Bloščica ponor and becomes active only at high waters, cavers named this tributary "dotok Bloščic" (= afflux of Bloščica). Sump was not dived yet and this connection was never proved by tracing tests but it seems to be possible. Near Vratca the main water course gets unusual underwater tributary that is well detected with SEC, T and pH measurement. Origin of this water is not interpreted yet. Lower downstream, right tributary at Medvodje contributes majority of water flow in Blata passage especially at middle water levels. According to water chemistry measurements (Prelovšek, unpublished) the portion to the all quantity of water in Blata can be from 43% at low water levels and up to 92% at high water levels. Just before the confluence with the brook from Pisani rov water course in Blata passage gets quantitatively quite unimportant left tributary from Markov rov.

Outflows of water in Pisani rov and Blata passage are unknown due to lack of discharge measurements. If they exist they are at least not visible. Contrary to Pisani rov and Blata passage water in the Jezerski/Glavni rov is lost at least at two places and probably joins the major water course between Ponor and Dežmanov rov, maybe also through V-rov. The latter contributes only few litres per second of water at low water levels. At middle-low discharges this water is very similar to the water which flows through Jezerski/Glavni rov. But in the case of heavy storms above Križna jama it erupt some m^3/s of turbid water. Clear water from the Jezerski/Glavni rov at the same time proves different catchment areas at high water levels. Water is therefore gathered through unknown passage between Lož polje and southern part of Bloke plateau.

Gradient of water flow in Križna jama is extremely low. Between 1st lake and Kalvarija the vertical difference equals only 2.6 m in the 1,200 m long Jezerski/Glavni rov (Planina, 1985). Thus the gradient is only 0.2%. In Pisani rov and Blata passage the gradient is due to some breakdowns some tenth of percent higher. The highest gradient is between 1st lake and Ponor (about 10%) and downstream from Dežmanov rov (about 5%).

4. Basic Physical and Chemical Characteristics of Waters in Križna jama

Physical and chemical characteristics of waters are the results of geological settings and hydrological conditions in different part of an aquifer. In Križna jama they are significantly influenced also from meteorological conditions outside the cave (Prelovšek, 2007).

A basic factor that defines physical and chemical properties of water in Križna jama is the origin of water. Since the water is autogenic by origin, we know that at the beginning it has to be infiltrated through epikarstic and vadose zone until it reaches the phreatic or epiphreatic zone near Križna jama. Due to the depth of roof (usually 150 – 200 m) such waters have very constant temperature through the year, they have high pressure of CO_2 and because they are near the equilibrium with respect to Ca^{2+} they have also a lot of dissolved carbonates.

Permeability of all four hydrological zones (soil, epikarstic, vadose and phreatic) is relatively high and mitigation of precipitation is weak in the case of Križna jama. Rapid response is possible because of the intensively karstified limestones and also dolomites above Križna jama. At the water level water flow is also not restricted because of well organized system of dendritic drainage system. Also more than 70 m sump between Križna jama and Križna jama 2 has an appropriate dimension to conduct low and middle discharges without special damming. Rapid reaction to strong precipitation in the Jezerski/Glavni rov was often observed by guides (Troha, 2005). But since the aquifer is also composed of fracture-matrix system with high water capacity, discharge after precipitation decrease very slowly. This leads to torrential character of waters in Križna jama with relatively long decline of discharge.

Water level at 1st lake fluctuates for several meters. In the case of extreme drought water level decreases for more than 5 m under the normal water level and the 1st lake can lose almost all water. At such hydrological condition the discharge in Jezerski/Glavni rov is between 1 l/s and zero. At high water levels water can rise for about 1 m in the 1st lake and flows into the Dežmanov rov under the Čimboraso. In such case discharge is about 2 m^3/s. In the case of extremely high water levels at 1st lake can rise up to 4 m. Water appears also in Cerarjeva dvorana and can flow over tourist path toward Kittlova brezna (Troha, 2005). Discharge at such water level is unknown since it occurs very rarely (about twice per hundred years) and it is extremely hard to be measured. Since the velocity of water is much reduced at such water levels, estimated discharge can be some m^3/s higher than at high water levels (2 m^3/s).

A high saturation index and a lot of dissolved carbonates are a result of infiltration through soil and epikarstic zone. Water that is flowing through the soil absorbs higher quantity of CO_2 than it is able to retain in the cave's atmosphere. Because of this we can expect oversaturated water. This is exactly the case of Križna jama where the flowstone deposition process is increased by intensively aeration of cave during the winter time (Prelovšek, 2007). Such aeration reduces CO_2 concentration in the karst massive (around Križna jama is about 2.000 ppm; Prelovšek, unpublished data) to nearly open atmosphere concentration (about 360 ppm). Just the opposite, underground waters of Bloščica and Farovščica has lower CO_2 concentrations due to superficial flow and therefore less dissolved carbonates. They does not deposit any flowstone even during low and middle water levels and but they can become slightly corrosive at high water levels (Prelovšek, 2006). Since these waters are not able to deposit flowstone we have another proof that water stream in the Križna cave is fed by primary infiltration through vadose zone.

The pH value is inadequately studied but an important chemical parameter in Križna jama. According to some periodical measurements it corresponds to water level fluctuation and meteorological conditions. At very high water levels pH value can be below 7.5. Lower pH values are observed also in summer time although the water level can be quite low. This is probably related to weaker degassing of CO_2 from the water. Higher pH values (above 8.0) were recorded at low water levels usually in winter time. If the water level is low and outside temperatures stays below 0° C for some days, pH value can rise even above 8.3. In such conditions we recorded also vast flowstone deposition.

5. Hydrological Conditions before the Holocene

From the hydrogeological point of view, passages and sediments in Križna jama show a very dynamic evolution. From the speleogenetical point of view it contains probably several phases of hydrological activity and inactivity of passages that is now reflected in some morphological and sedimentological structures.

The oldest water flow through Križna jama is seen through the dimensions of now inactive passages. Before the formation of Jezerski/Glavni rov water was flowing from Kalvarija through Suhi rov, 1st lake, Medvedji rov, Cerarjeva dvorana toward Kittlova brezna or toward north, where we can follow several collapsed dolines on the surface. This old water course was probably abandoned due to several collapses in Cerarjeva dvorana and especially the big breakdown between Suhi rov and 1st lake. The breakdown is visible also on the surface near the quarry as collapsed doline.

According to the investigations of Gospodarič (1974) we know for sure that Pleistocene water course was characterized by a strong allogenic input of water. This is proved by sedimentological investigation of allogenic sediments found in Pisani rov, Jezerski/Glavni rov and on some places in Blata passage. The origin of this material (chert and Upper Triassic dolomite) is namely northern part of Bloke plateau. It is possible that the ponors of Bloščica near Velike Bloke were blocked by allochtonous sediment and thus hydrologically not active at that time. As a result, Bloščica had to flow further to the south. The ponors of Bloščica and Farovščica were probably near present-day polystyrene deposits (1 km southwestern from Fara), from where it is possible water connection with Pisani rov in Križna jama. Catchment area of waters that flew through Križna jama was not just on Bloke plateau since Gospodarič (1974) detected also gravel from the near surrounding of Križna jama (Lower Jurassic dolomite and oolithic bauxite). The age of this phase is definitely older than the oldest dated sediment in Medvedji rov, this is 146,000 ± 14,000 B.P. (Ford & Gospodarič, 1989; Zupan Hajna et al., 2008) or 46,700 +2,400/-1,800 B.P. (Rabeder & Withalm, 2001; Pohar et al., 2002). In that time, velocity of water was much higher since the cave was without dams and other restrictions. Lower parts of the passage were covered with more than 2 m thick gravelly sediments (to the altitude 617 m a.s.l. near 1st lake). Pebbles more than 10 mm in diameter also show that they were moved as bedrock and not in suspension like now. Water velocity has at least 1 m/s, this is much higher as today (Gospodarič, 1974). Later, the geomorphological and hydrological conditions changed so severe, that Bloščica probably reactivated previously blocked ponors. Reactivation of present-day ponors of Bloščica has broken off transport of sediment from northern Bloke plateau to Križna jama. In the present time, only very high waters of Bloščica flow further to the south toward polystyrene deposits, but such waters do not transport sand or gravel any more. This change into the slow water flow was sudden, since Gospodarič (1974) nowhere noticed normal graded bedding. In this phase water deposited about 3 m of loamy sediments to the altitude about 620 m a.s.l. Some meters higher deposition took place in side passages (Medvedji rov, Suhi rov, probably Cerarjeva dvorana). All these passages had to be exposed to frequent inundation which deposited fine grained material to the altitude about 624 m a.s.l. near 1st lake and completely blocked Ponor (Gospodarič, 1974).

Later, Križna jama has to be hydrologically inactive and was used as a lair for *Ursus spelaeus*. According to U/Th datations made by Ford & Gospodarič (1989) this happened before 146,000 ± 14,000 a B.P. If the bones were intruded between two dated flowstone, hydrologic inactivness of Križna jama could happen after 126,000 ± 11,000 a B.P.

The final two hydrologic phases started in Würmian glacial and lasts even now. In the glacial water was erosive and corrosive. As a consequence passages were widened and deepend. Due to climatic changes at the end of Würmian glacial water chemistry changed so much that present-day hydrochemical process is mainly flowstone deposition out of usual underground stream of Farovščica and Bloščica brooks.

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Sedimentary Deposits in Kittl's Bear Gallery in Križna Jama Cave (Slovenia)

by

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Kralj, P., 2014. Sedimentary Deposits in Kittl's Bear Gallery in Križna Jama Cave (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:35 – 43, Wien.

Zusammenfassung

Die Križna jama ist eine Karsthöhle, die durch fließendes Wasser und somit durch die Dominanz fluviatiler Sedimente geprägt wird. In trockenen Galerien, wie eben Kittls Bärenhöhle, kommen typischerweise extrem schlecht sortierte und schwach stratifizierte Höhlensedimente vor. Sie entstehen durch Deckenbrüche und von den Höhlenwänden brechendem Material, episodische Überflutungs-Events, authigenische Calcit-Ausfällung und der Ablagerung von Höhlenbärenresten.
Während der Überflutungs-Events wurden neue, feinkörnige fluviatile Sedimente in die Galerie eingebracht und die davor abgelagerten Sedimente wurden erodiert und ausgeschwemmt oder umgelagert. Die Höhlensedimente in Kittls Bärenhöhle erinnern damit stark an die zuvor untersuchten Sedimente aus der Potočka zijalka, der Herkova jama, und vor allem an die aus der Ajdovska jama.
Schlüsselwörter: Höhlensedimente, Karst, fluviatile Sedimente, Bärenhöhle, Slowenien

Abstract

Križna jama is a karstic cave, characterised by flowing water and dominating fluvial sedimentation. In dry galleries – like Kittl's Bear Gallery – typical, extremely poorly sorted, and massive to faintly stratified cave sediments occur. They developed by free-fall from the cave walls and ceiling, episodic flooding events via conduits, authigenic calcite precipitation, and settling of cave bear remains. During flooding events, new fine-grained fluvial material was brought in the gallery, and the pre-existing deposits were eroded and redistributed. Cave deposits in the Kittl's Bear Gallery resemble to previously studied cave sediments from the Potočka zijalka, Herkova jama, and particularly Ajdovska jama caves.
Keywords: cave sediments, karst, fluvial sediments, cave bear site, Slovenia

Izvleček

Križna jama je kraška jama, ki jo odlikujeta tekoča voda in značilna rečna sedimentacija. V suhih dvoranah kot je naprimer Kittlova medvedja dvorana, se pojavljajo značilni jamski sedimenti, ki so ekstremno slabo sortirani ter masivni do nejasno plastoviti. Nastali so s prostim padom odlomkov prikamnine s stropa in sten, z epizodičnimi poplavami preko kraških ponorov in požiralnikov, z izločanjem kalcita ter s kopičenjem kostnih ostankov jamskega medveda. Poplavni dogodki so v sicer suho dvorano prinašali nov rečni material, hkrati pa so erodirali in presedimentirali stare sedimente. Jamski sediment v Kittlovi medvedji dvorani je zelo podoben tistim, ki smo jih našli v drugih jamah – Potočki zijalki, Herkovi jami in predvsem Ajdovski jami.
Ključne besede: jamski sedimenti, kras, rečni sedimenti, medvedja jama, Slovenija

1. Introduction

The Križna jama cave at Lož (Fig. 1) is one of several attractive phenomena developed in the area of classic karst in Southern Slovenia. The cave consists of the main gallery and several smaller galleries and channels attaining all together a length of over 8 km. The main gallery is characterised by flowing water whilst the smaller ones are »dry« most of the time, and may be flooded only in the periods of heavy rains. The cave is hydrologically connected to the main recharge area of the Bloška polica plateau in the north-east, and to the westward positioned discharge area of the Cerkniško polje carstic lowland with the Lake of Cerknica in its

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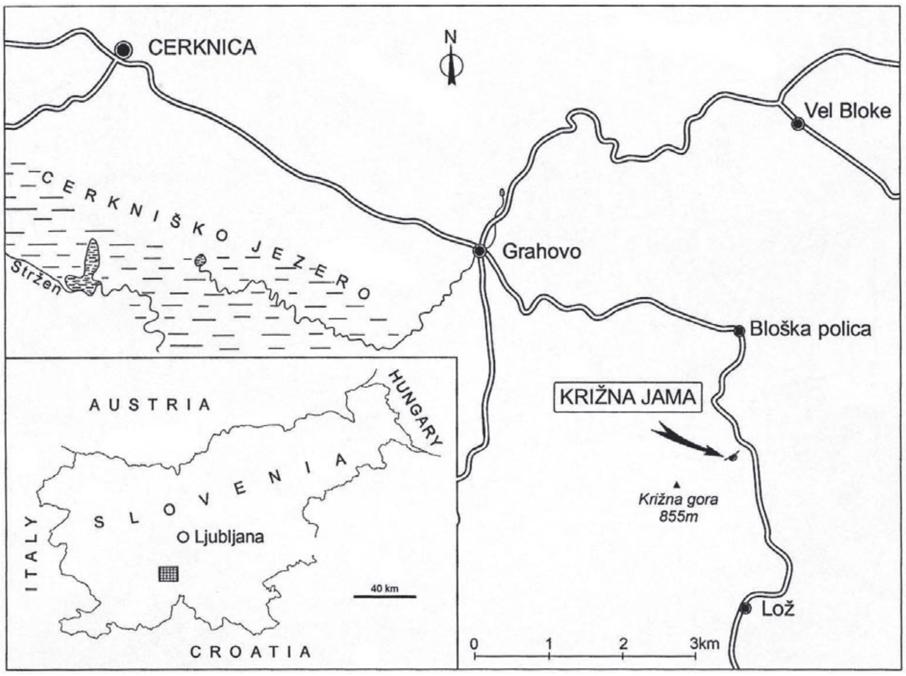

Figure 1: Geographic position of the Križna jama cave.

central part (Prelovšek et al., 2008). Flowing waters running through the cave are the most important agent in sedimentation process forming channel-lag, levee, point bar and swale-fill deposits. During high-water regimes, flood suspensions reach »dry« galleries via conduits and form fine-grained laminated and thinly stratified deposits. Free-fall material detached from the wall ceiling and walls is significant, too, and can be distinguished from fluvial deposits by essentially extremely angular shape. After deposition, free-fall material can be subjected to mechanical decomposition and eventual redistribution and rounding by fluvial currents. Bauxite and limonite ooids occur mainly in the granule size and are reworked clastic material in origin.

Authigenic mineral deposits are dominated by stalactites, stalagmites and aragonite and calcite sinter precipitating from waters leaking through fracture systems in the cave walls and ceiling. Small-scale dams in fluvial channels slow-down the flow and produce small lakes. Their bottom is covered by fragile aragonite sinter which is still growing. Phosphates occur as an alteration product of bone material. When replacing bones, they are commonly crystallised as apatite, carbonateapatite or fluorapatite. Redistributed phosphates are scarce, and as amorphous or very poorly crystallised colloidal material form thin lenses in clayey and silty deposits. Manganese oxides are rare in occurrence and commonly poorly crystallised, too.

This contribution is focused on sedimentary deposits in Kittl's Bear Gallery which was the most important excavation site in our 1999 campaign. Sediment composition, structure and texture were studied in order to recognise transporting agents, depositional environment, and syn- and post-sedimentary reworking processes that influenced redistribution of fossil bone material.

2. Cave Deposits

Cave deposits in Križna jama were previously extensively studied by Gospodarič (1974). Quaternary fluvial sand and silt prevail. Average sandy sediment contains up to 10 wt. % of silt and clay. The composition is dominated by carbonate (about 70 wt. %), whilst quartz (20 wt. %) and limonite ooides (10 wt. %) are subordinate constituents. Only locally, quartz- and limonite ooid-dominated sands (Plate 1, figs. 1, 2) occur, containing less than 10 wt. % of carbonate only. The sands are the most widespread levee and point bar deposits in the water-dominated galleries. Lithification of sands is not very common. Cement consists of bauxite (Plate 1, fig. 3) or carbonate – calcite or aragonite (Plate 1, fig. 4).

In »dry« galleries, finer-grained sand occurs. It commonly contains higher proportions of silt, although its composition is similar to the coarser varieties. Carbonate is the main constituent; quartz, limonite and illite/muscovite follow in a decreasing abundance order.

Gravel and conglomerate are channel deposits. Sporadic erosional remains of conglomerate occur between Dežman's Gallery and Mt. Crystal, and along the shoreline of the First Lake. In the first locality it consists of bauxite ooids up to 1 cm sized (about 65 wt. %) that are set in a sandy-silty matrix (about 22 wt. % of sand and 13 wt. % of silt). Carbonate cement may partially fill primary pores. Conglomerate occurring in the second locality contains less than 30 wt. % of ooids in average, the rest are mainly the grains of dolomite.

Bauxite and limonite ooids are common in the water channels (Plate 1, figs. 5, 6). Being heavier than the rest of the load, they can not be flooded over the sinter dams but are concentrating as the channel lag deposit. They are eroded from some pre-existing sedimentary deposits that

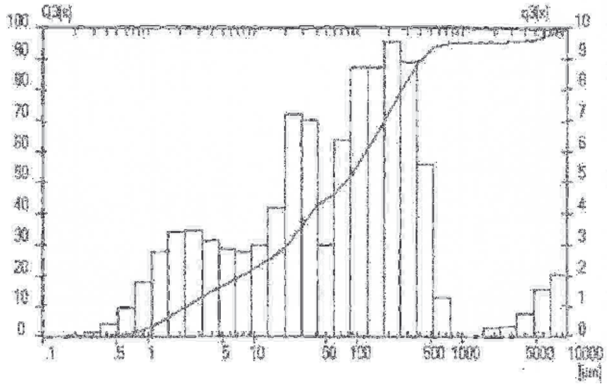

Figure 2: Bulk sediment distribution for the sample KJ 03.

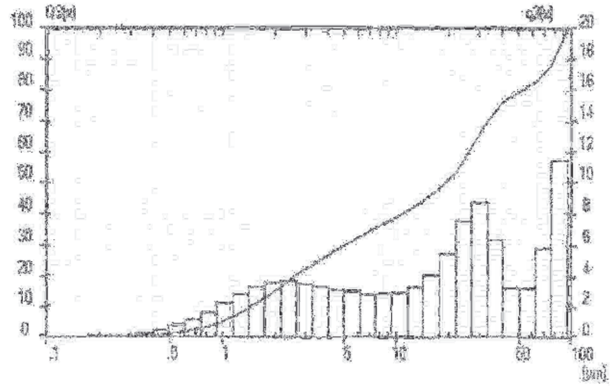

Figure 3: 0 – 100 µm fraction distribution for the sample KJ 03.

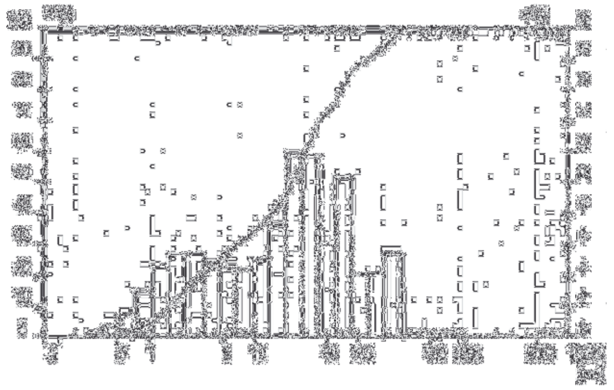

Figure 4: Bulk sediment distribution for the sample KJ 06.

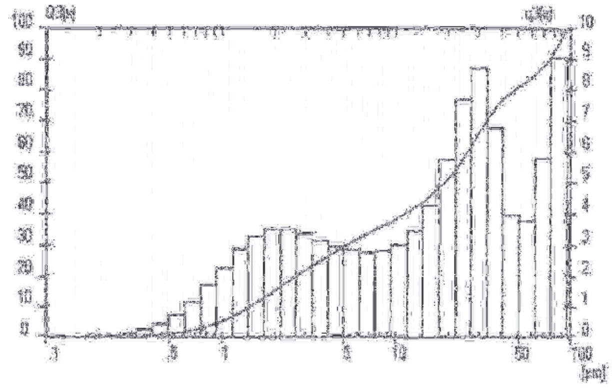

Figure 5: 0 – 100 µm fraction distribution for the sample KJ 06.

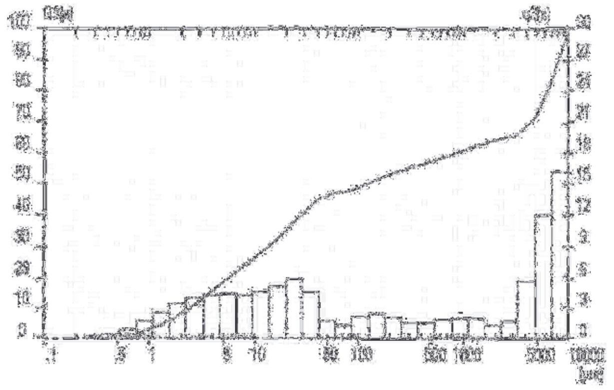

Figure 6: Bulk sediment distribution for the sample KJ 13.

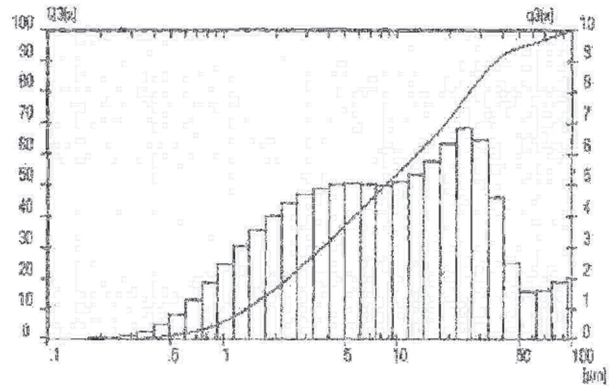

Figure 7: 0 – 100 µm fraction distribution for the sample KJ 13.

underwent erosion and reworking, and are not authigenic formations in the cave environment. If flooded in a small sink (Plate 1, fig. 7) exposed to constant dropping from the leaking walls and ceiling, they may become concentrically coated by aragonite or calcite (Plate 1, fig. 8).

3. Sediments in Kittl's Bear Gallery

Kittl's Bear gallery is one of smaller galleries situated close to the cave entrance. Today, the gallery is essentially dry. The water invades the cave during high water regimes via narrow conduits. The sediments are faintly laminated and thinly to medium bedded. Lamination and bedding is mainly related to a slight change in the grain-size, and very rarely, to the content of the sediment constituents.

Grain-size analysis (Table 1) indicates that the sediments are mixtures of silt, sand, gravel and clay. The actual amount of gravel fraction is uncertain as the sampling in the profile did not permit to gather the quantity sufficient for a reliable analysis. Nevertheless, the majority of the analysed samples are silts, most commonly sandy silts, or

Sample	Station	Depth (cm)	Clay < 2 µm	Silt 2 – 63 µm	Sand 63 µm – 2 mm	Gravel 2 – 63 mm
KJ 03	1	50 – 65	8.3	38.4	48.6	4.7
KJ 04	1	65 – 70	10.9	56.4	32.7	0
KJ 05	1	70 – 90	10.6	61.4	28.0	0
KJ 06	2	150 – 160	13.3	63.8	22.9	0
KJ 07	2	140 – 150	11.3	68.8	19.9	0
KJ 08	2	175 – 185	9.3	77.8	12.9	0
KJ 09	3	0 – 20	7.5	45.4	30.7	16.5
KJ 10	3	20 – 30	13.5	65.5	20.0	1.0
KJ 11	3	30 – 40	3.1	33.8	26.2	36.9
KJ 12	4	180 – 215	7.2	43.0	15.0	34.8
KJ 13	5	20 – 50	7.9	39.1	17.0	36.0
KJ 14	5	50 – 70	4.0	26.9	10.0	59.1

Table 1: Grain-size distribution for the studied samples from the Križna jama cave.

Sample	Station	Depth (cm)	Clay < 2 µm	Silt 2 – 63 µm	Sand 63 µm – 2 mm
KJ 03	1	50 – 65	8.7	40.3	51.0
KJ 04	1	65 – 70	10.9	56.4	32.7
KJ 05	1	70 – 90	10.6	61.4	28.0
KJ 06	2	150 – 160	13.3	63.8	22.9
KJ 07	2	140 – 150	11.3	68.8	19.9
KJ 08	2	175 – 185	9.3	77.8	12.9
KJ 09	3	0 – 20	9.0	54.2	36.8
KJ 10	3	20 – 30	13.6	66.2	20.2
KJ 11	3	30 – 40	4.9	53.6	41.5
KJ 12	4	180 – 215	11.0	66.0	23.0
KJ 13	5	20 – 50	12.3	61.1	26.6
KJ 14	5	50 – 70	9.9	65.6	24.5

Table 2: Gravel-free grain-size distribution for the studied samples from the Križna jama cave. The gravel fraction was sieved-off from the bulk sample and the grain-size distribution recalculated to 100 wt. %.

more rarely, gravelly (sandy) silts. Only one of 12 samples is sandy silty gravel.

The content of gravel fraction is not representative owing to insufficient availability of the sediment sampled in the profiles in our digging stations. The gravel mainly originates from the walls and ceiling and forms a unique population. The remaining sand, silt and clay fractions represent fluvial material, and also, the material developed by mechanical decomposition of the wall and ceiling rock and/or by authigenic calcite and limonite growth. Uneven grain-size distribution indicating the presence of different populations has been observed for both, bulk and gravel-free samples. Sorting is extremely poor for the bulk samples and somewhat better for the gravel-free samples (Table 2, Figs. 2 – 7). Clay and very fine to fine silt (0,3 – 10 µm) population is very uniform for the majority of the studied samples and has the median of about 2,2 µm. Medium and coarse silt population has the median of about 30 µm, and very fine sand at about 80 µm. Medium- to fine-grained sand is typically composed of fluvial and reworked free-fall material, and for that reason, the population is very commonly bi-modal. Coarser populations have a less uniform distribution and median values, and mainly originate from free-fall from the cave walls and ceiling.

Mineral composition recognised by X-ray diffraction method is relatively uniform. In bulk samples, calcite is the most abundant mineral, the amount ranging from 50 wt. % to 85 wt. %. The other very variable component is hydroxyl-carbonate apatite which originates from the alteration of bone material; fluorapatite is less abundant and replaces fossil teeth. Some laminae in silty layers consist of authigenic apatite, but it is poorly crystallised, gelatinous and non-detectable by X-ray diffraction. In

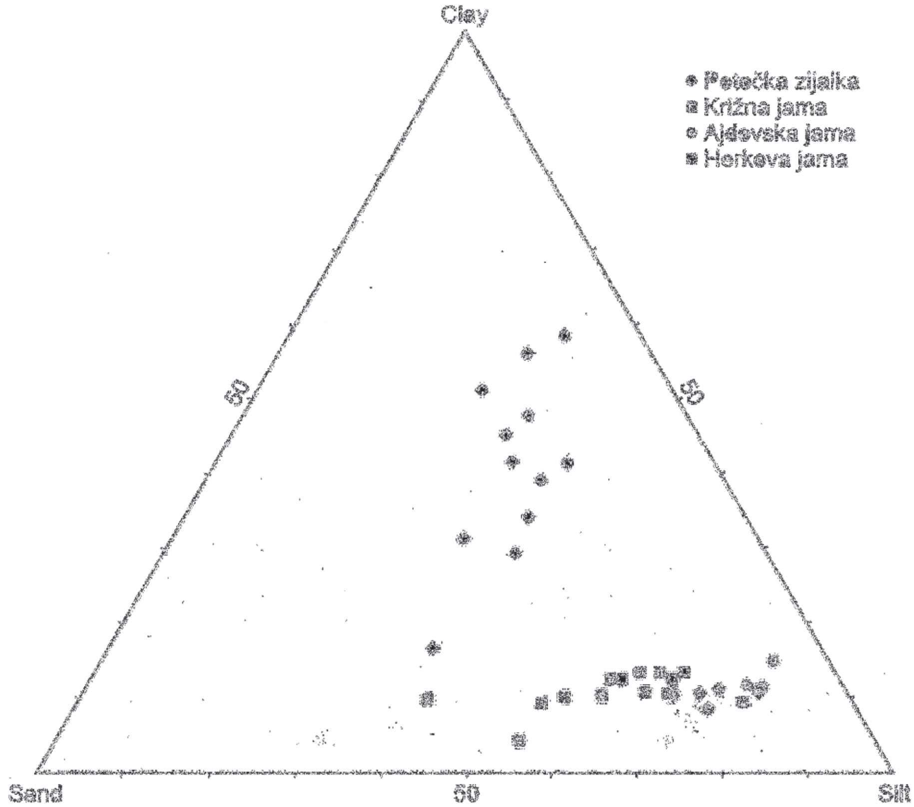

Figure 8: Clay-Silt-Sand triangle with the position of samples studied in Slovenian karstic caves with cave bear remains.

the sand and silt fraction, quartz is the most abundant mineral although its amount is variable – from 30 wt. % to over 60 wt. %. Calcite is still an important constituent and commonly ranges from 25 wt. % to 40 wt. %. Muscovite/illite amounts up to 20 wt. %, whilst chlorite is less abundant, commonly below 10 wt. % of the bulk sample. In the sand and silt fraction, limonite particles also occur in the form of xenomorphic and poorly crystallised grains. The clay fraction may still contain up to 20 wt. % of calcite, although the most abundant constituents are illite and mixed layered illite/montmorillonite and chlorite/montmorillonite. The clay fraction was studied in oriented and glycolised samples. In suspended form, clay minerals underwent extreme coagulation, very possibly owing to the presence of phosphate colloidal particles.

4. Conclusions on Transport and Post-sedimentary Redistribution of Sediments in Kittl's Bear Gallery

Based on sedimentological analysis of cave deposits in the Stations 1 – 5 in the Kittl's Bear Gallery, in average about 20 wt. % originates from free-fall, about 70 wt. % was derived by fluvial currents during flooding periods, about 5 wt. % is authigenic – mainly calcite sinter, and about 5 wt. % are fossil remains.
Predominant massive structure, grain-size distribution indicating the presence of up to six populations, extremely poor sorting, coexistence of very angular and rounded grains, as well as the sediment composition reveals a complex formation history. The majority of fine-grained sediment (clay, silt and fine sand) was transported by ephemeral flooding episodes that entered the gallery via conduits. The bulk of coarse sediment (gravel) originates from free-fall – the detachment of the cave walls and ceiling. Along geochemical boundaries, calcite precipitates and forms thin sinter veneers. Flooding episodes brought new clastic material in the gallery, but also disturbed the existing deposits owing to a turbulent current character. Free-fall material, broken sinter veneer, bone material and eroded old flood deposits were redistributed and settled again as reworked sediment mixture that lacks of internal stratification and is extremely poorly sorted.
Although the majority of Križna jama cave is characterised by flowing water and fluvial sedimentation, typical cave sediments have been developed in the dry Kittl's Bear Gallery. They closely resemble the sediments studied in some other Slovenian karstic caves with Pleistocene fossil fauna remains, like Potočka zijalka (Kralj, 2004), Herkova jama or Ajdovska jama (Fig. 8). The closest resemblance can be identified for the Ajdovska jama cave (Kralj, 2011) as it is strongly influenced by flooding events via conduits and has mineralogically similar source rocks.

5. Acknowledgements

I kindly acknowledge Alojz Troha from Bloška Polica to make available his photo heritage for this publication. I am thankful to Slovenian Research Agency ARRS for funding my work.

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PLATE 1

Fig. 1 Fluvial pebbly sand with bauxite ooids and fragments of broken sinter. The ooid sizes range from about 1 – 3 cm.

Fig. 2 Partially lithified pebbly sand.

Fig. 3 Bauxite-cemented sandy conglomerate.

Fig. 4 Calcite-cemented sandy conglomerate.

Fig. 5 An underground lake dam covered by aragonite.

Fig. 6 Concentration of eroded bauxite ooids (pebbles) in the dam fronts.

Fig. 7 Authigenic aragonite forming covering the dam surfaces. Aragonite crystal sizes attain up to some mm.

Fig. 8 Authigenic aragonite ooids, 1 – 2 cm sized.

Photos: © by Alojz Troha (Bloška Polica, Slovenia)

PLATE 1


Fig. 1


Fig. 2


Fig. 3


Fig. 4


Fig. 5


Fig. 6


Fig. 7


Fig. 8

Recent Fauna of the Cave Križna jama in Slovenia

by

Boris Sket [1)] & Fabio Stoch [2)]

Sket, B. & Stoch, F., 2014. Recent Fauna of the Cave Križna jama in Slovenia. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:45–55, Wien.

Zusammenfassung

Die Križna jama ist eine Höhle in SW-Slowenien und hat eine Gesamtlänge von ca. 8 km die von mehreren Ursprüngen mit Wasser versorgt werden. Es fehlt ihr aber ein Strom eines permanenten (!) Schwindebaches. Daher ist diese Höhle oligotroph und ihre Fauna besteht überwiegend aus Troglobionten. Die meisten nicht-troglobionten Tiere leben terrestrisch und nahe dem Eingang. Wir konnten insgesamt 32 aquatische und 18 landlebende troglobionte Taxa feststellen, was eine der artenreichsten troglobiotischen Faunen der Welt darstellt. Die Križna jama ist Typlokalität für acht aquatische und drei landlebende troglobionte Arten.
Schlüsselwörter: Höhlenfauna, unterirdische Biodiversität, Dinarischer Karst

Summary

Križna jama is a cave in SW Slovenia, with 8 km of corridors, fed by different waters, but without a permanent sinking stream. The cave is therefore generally oligotrophic and its fauna consists mainly of troglobionts; most non-troglobionts are terrestrial and limited to the entrance area. We could list 32 aquatic and 18 terrestrial troglobiotic species which is one of the richest troglobiotic faunas in the world. This cave is the type locality for eight aquatic and three terrestrial troglobiotic taxa.
Keywords: cave fauna, subterranean biodiversity, Dinaric karst

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Izvleček

Križna jama na jugozahodu Slovenije ima približno 8 km hodnikov, ki jih napajajo različne vode, vendar je brez stalne ponikalnice. Zato je jama na splošno oligotrofna, njeno favno pa sestavljajo predvsem troglobionti; največ ne-troglobiontov je kopenskih in omejenih na območje vhoda. Naštetih je 32 vodnih in 18 kopenskih troglobiotskih vrst, kar predstavlja eno najbogatejših troglobiotskih favn na svetu. Ta jama je tudi tipska lokaliteta za 8 vodnih in za 3 kopenske troglobiotske taksone.
Ključne besede: jamska favna, podzemeljska biotska pestrost, Dinarski kras

1. Introduction

Križna jama is a cave of more than 8 km of corridors, of which only a small part are hydrologically inactive, with only sparse pools of percolated water. Streams of different origin flow in the remaining parts of the cave, but none of them is a permanent sinking river bringing underground much food and aquatic fauna from the surface. The streams flow mainly from the inner parts towards the entrance area where they sink into a lower, less accessible level.
The stream in the main corridor (Glavni rov) is at low water levels partitioned by low sinter dams into a series of clear ‚lakes', mainly with a sandy bottom. During a rainy event, this stream may rise within some hours by a couple of meters and became highly turbid. Such a strong torrent makes inner parts of the cave inaccessible; thus, some details of the hydrological situation within the cave are unknown. The origin of the main channel and its stream is at Kalvarija, where two channels merge. From the right channel (called Blata) a small brook is flowing between high loam deposits and with a loamy or sandy-loamy bottom. This brook originates from some brooklets of percolated waters and the intermittent sinking brook

Bloščica-Farovščica (Kogovšek et al., 2008). More in detail, hydrographical situation in the cave is quite complicated (Prelovšek, 2007).
The cave is in a comparatively natural status, although the influence from the Bloke Plateau can sometimes be felt, turning the clear lakelets turbid. Recently, a weak influence from the periodical sinking stream Farovščica was traced (Kogovšek et al., 2008). A detailed geomorphological and hydrographical description of the cave is given by Pohar (this volume).
No ecological investigations have been done in the cave. Data given are results of numerous visits since 1850 (Wolf, 1938) till now, as well as some detailed faunistic reviews of ourselves (started in 1970ies). Very rich data are given by Joseph (1882). He is mentioning the cave as Mrzla jama, a name more used in the past. Križna jama = Mrzla jama pod Križno goro (cadastral number 0065) is one of 11 registered caves in Slovenia (JZS 2008) called »mrzla jama« (= »cold cave« !); to make the confusion perfect, there are two more within the reach of some kilometers to Križna jama (Mrzla jama pri Ložu c.n. 0079 and Mrzla jama pri Bločicah c.n. 1176). In modern times, most data for Gastropoda have been given by Kuščer (1928, 1932) and Bole (1967, 1979); for Oligochaeta by Sp. Karaman (1978) and Martinez-Ansemil et al. (1997); for Malacostraca by St. Karaman (1952) and Strouhal (1928); for Coleoptera by Jeannel (1924, 1928), Mueller (1923) and Pretner (unpublished). Sket (1986) published a popular paper regarding distribution of fauna within the cave. One has to note that Wolf (1934–1938) is imputing Joseph also some data which could not be found in the cited paper (Joseph, 1882).

2. Results

2.1. Faunal List

The cave fauna recorded up to now from Križna jama (excluding taxa identified at the family or higher level) includes 36 aquatic and 47 terrestrial species (Tab. 1). At least 32, i.e. close to 90% of aquatic species (or races) are troglobiotic; much higher is the number of non-troglobiotic species (mainly trogloxenes) in the terrestrial fauna, with only 18 troglobiotic species. Križna jama is the type locality for 8 aquatic and 3 terrestrial troglobiotic taxa.
The first author to report species from the cave was Joseph (1882); unfortunately, some of the taxa he described have never been mentioned again; since Joseph is a very unreliable author (St. Karaman, 1950), such data are marked in the list with ‚J'. To report an example for aquatic fauna, the first subterranean copepod from Križna jama was cited by Joseph as "*Cyclops hyalinus*". Apart from the fact that the name established for this species by Joseph is not valid, being pre-occupied by *Cyclops hyalinus* Rehberg 1880, the old-fashioned original description allows only to recognize that it refers to a cyclopoid copepod: several species are present in the cave (Chappuis, 1933; Petkovski, 1983 and present researches), and Joseph's citation has no scientific meaning.
The genus *Lessinocamptus* is reported here for the first time from Slovenia: the only described species are known from the Lessinian mountains (Central Pre-Alps in Italy: Stoch, 1997). Several groups need to be studied in detail and taxonomic problems still remain; in this context the list is far from being exhaustive. As regards Oligochaeta, Sp. Karaman, in her doctoral dissertation dealing mainly with the material from the Postojna-Planina Cave System, could see only few specimens of *Spirosperma* and *Rhyacodrilus* spp. from Križna jama, therefore a confusion with the later (Martinez-Ansemil et al., 1997) described species is not to be excluded. Ostracods are present in most of aquatic habitats in the cave, but the material is still in study. Citations of Collembola and Diptera need to be re-examined and completed. The list of some well-studied taxa may be incomplete as well (for example for Copepoda and Araneae); also the Coleoptera, the most well-known group in Slovenian caves, need to be checked in detail.

2.2. Distribution of Terrestrial Fauna

The entrance corridor of Križna jama is very wide, the daylight penetrates here far inside. The parietal fauna has not been paid a special attention, but it is composed of usual members, mainly subtroglophiles: the lepidopterans *Scoliopteryx libatrix* and *Triphosa dubitata* are very common on the walls during winter; the cave-cricket *Troglophilus* sp. and the Trichoceridae dipterans (both not identified at species level) are present as well. In the humus rich bottom, enriched by decaying wood and other debris, probably eutroglophilous millipeds *Brachydesmus* sp. (in the past identified as *B. subterraneus*) and the extremely generalist mite *Schwiebea cavernicola* may be numerous; less common are the beetles *Laemostenus elongatus* and *Laemostenus schreibersii*.
In the corridors between the entrance and the first lake (Prvo jezero) are relatively (!) common three species of beetles. *Bathyscimorphus trifurcatus* and *Typhlotrechus bilimeki* may occur very close to the entrance but often hidden on the bottom, while *Leptodirus hochenwartii* is more lucifugous and may be dwelling on exposed cave walls deeper in the cave. The other coleopterans are very rare.
In deeper parts of the cave, behind the first lake, the terrestrial fauna is even much scarcer. Some specimens may be met where occasional organic debris accumulate or at the water edge, but even to usual baits (of putrescent meat) only single individuals are coming. Most common are Collembola and Diplura. Inhabitants of these parts of the cave are also the large woodlice *Titanethes* sp., the spiders *Stalita* and *Parastalita*, the beetles *Leptodirus* and *Typhlotrechus*; extremely rare are the pseudoscorpion *Neobisium*, the millipedes *Brachydesmus* and *Attemsia* and tiny snails of the genus *Zospeum*. All these animals may be found also closer to the entrance. Any other terrestrial animal can occasionally, very rarely, be met in different places within the cave.

Areas close to the entrance of Križna jama are recognized as a particularly important hibernating sites of the lesser horseshoe bat *Rhinolophus hipposideros*. This species never forms such dense agglomerations as some others, which is also reflected by the distribution of guano deposits. Besides this one, at least six additional bat species (Presetnik in CKFF et al., 2008) occur in this cave; they are much less numerous. The bat tick *Ixodes vespertilionis* may be seen here.

2.3. Distribution of Aquatic Fauna

In puddles on loam and in small rimestone pools (gours), fed by percolated water, some specimens of small crustaceans may be found. The small niphargid *Niphargus wolfi* and the larger *N. stygius* are quite common in these habitats, together with several oligochaetes and copepods like *Elaphoidella* spp., *Speocyclops infernus*, *Acanthocyclops kieferi*. Some others may be vehiculated from the subterranean river in the puddles during the floods. Similarly scarce is also the fauna of larger waters in Pisani rov. In those parts of the corridor Blata, where the bottom consists of a very loose silt mixed with some sand, the large troglobiotic oligochaete *Delaya bureschi* is comparatively common and so are unidentified, probably semi-terrestrial Enchytraeidae. In lower parts of the stream in Blata and in the main corridor below this (i.e. around Kalvarija), the stocky amphipod *Niphargus orcinus* and the isopod *Monolistra racovitzai* are comparatively densely present.
However, *N. orcinus*, *Belgrandiella* spp. and *Trichodrilus ptujensis* can equally be met along Blata and Glavni rov, together with several copepod species closely linked to karstic waters, like *Acanthocyclops troglophilus* and *Diacyclops charon*.
In Stransko jezero, we can find small amounts of organic debris coming from surface (particles of fallen leaves and similar). The population of aquatic snails is the richest on stones here, although they occur also elsewhere and their empty shells may be found deposited in calm places further down in the cave stream. Beside numerous prosobranch species, one can find here also *Zospeum exiguum*, an aquatic species of the otherwise terrestrial genus of pulmonates. The slender amphipod *Niphargus stygius* is also most common in Stransko jezero and in Blata below it.

3. Discussion

Although no exact measurements were done, Križna jama may be classified as oligotrophic and obvious food scarcity was noted throughout the cave, in the water and outside it. The only exception is the wide entrance corridor, which is also naturally illuminated, thus being outside the real cave environment. This is probably the main reason (compare Sket, 1977) why there are so few non-troglobiotic elements present. Plecopteran larvae were found in the main stream, but once this was a group of very young ones (still unidentifiable), another time a single grown up (still larval) nemourid. The low number of aquatic trogloxenes, the near absence of eutroglophiles and the very high number of troglobionts is usually considered as a good indicator of a good quality of the subterranean waters.
The troglobiotic fauna does not occur in high density as well, but it is very diversified. Culver & Sket (2000) were able to list for the entire world 20 cave systems with 20 or more troglobiotic animal species; six of them host 40–84 species. Križna jama appeared with 50 troglobiotic species among the richest caves in the Dinarides and in the world.
Being within the Ljubljanica drainage system, this cave is devoid of the cave tube worm (*Marifugia cavatica* Absolon & Hrabe), present in most other parts of the Slovenian karst. More surprising is the absence or probable absence in this řich cave of two holodinaric elements which are otherwise present also in most parts of the Ljubljanica drainage: the cave salamander *Proteus* and the cave shrimp *Troglocaris*. *Proteus* is however mentioned by Joseph (1882), under Fitzinger's (1850) name *Hypochthon freyeri*. One has to note that Fitzinger described this supposed species from the far away locality in Dolenjsko, and that neither Fitzinger nor any other author does mention *Proteus* for Križna jama later. Therefore, the locality was listed by Sket (1997) as ‚most probably erroneous'. On the other hand, there are some more reliable localities in the vicinity, among them even the spring Štebrk (Fitzinger, 1850; Sket, 1997) which is hydrographically linked with Križna jama (Kogovšek et al., 2008). Thus, we cannot exclude the presence of *Proteus* also in Križna jama. But no *Troglocaris* was ever reported from the wider Lož area (Sket & Zakšek, 2008:fig. 2). The reason for this deficiency might be the same as for the absence in the neighboring Cerkniško jezero of any Thiaridae, Neritidae and Unionidae (Bole, 1979).
Biogeographical relationships of some aquatic troglobionts here are trans-Dinaric (i.e. their distribution ranges extend beyond the Dinaric region); however, some endemics are present as well. Most oligochaeta can be considered ecological generalists, present in karstic and interstitial waters of a wide part of Europe; perhaps, part of this fact may be due to a poor taxonomic practice. For example the tubificid worm *Tubifex pescei* is known from southern Italy as well; within Haplotaxidae, *Delaya bureschi* is present in Croatia, Romania, Bulgaria, Macedonia and dubitatively in Greece; within Lumbriculidae, *Trichodrilus strandi* is known from France to Slovakia. As far as we know, *Rhyacodrilus omodeoi* is endemic.
The gastropod genus *Belgrandiella* is distributed in NW Dinarides and in Southern Alps. Three co-occurring species are evidently a result of an intense speciation in the Cerknica-Vrhnika area (Bole, 1967); their sympatry may well be of a secondary origin, while the flock encompasses a total of 7 species. *Zospeum exiguum* is a narrow endemic of this area (Bole, 1979); surprisingly, it is an aquatic species of a terrestrial (or sometimes amphibious) genus. Most of the copepods inhabiting groundwater habitats

	AQUATIC
	CILIATA
**	*Lagenophrys monolistrae* Stammer 1935
	TURBELLARIA
**	*Dendrocoelum* cf. *spelaeum* (Kenk 1924)
**	*Stygodyticola hadzii* Matjašič 1958
	GASTROPODA
**	*Belgrandiella superior* (Kuščer 1932)
**T	*Belgrandiella crucis* (Kuščer 1928)
**T	*Belgrandiella schleschi* (Kuščer 1932)
**	*Paladilhiopsis* sp.
**	*Hauffenia michleri* Kuščer 1932
**T	*Zospeum exiguum* Kuščer 1932
	OLIGOCHAETA
**	*Delaya bureschi* (Michaelsen 1924) [Plate 1:1]
**	*Trichodrilus strandi* Hrabe 1936
**	*Trichodrilus ptujensis* Hrabe 1963
**	*Trichodrilus pragensis* Vejdovsky 1876
**T	*Rhyacodrilus omodeoi* Martinez-Ansemil, Sambugar & Giani 1997
?	*Rhyacodrilus maculatus* Sp. Karaman 1977
**	*Rhyacodrilus sketi* Sp. Karaman 1974
	Stylodrilus heringianus Claparéde 1862
**	*Tubifex pescei* (Dumnicka 1981)
?	*Spirosperma velutinus* (Grube 1879) *Buchholzia* sp. (Enchytraeidae)
	OSTRACODA
**	*Sphaeromicola stammeri* Klie 1930
?	Ostracoda gg. spp.
	COPEPODA
**	*Elaphoidella jeanneli* (Chappuis 1928)
**	*Elaphoidella stammeri* Chappuis 1936
**T	*Lessinocamptus* n. sp. Stoch unpubl.
**	*Bryocamptus* (*Rheocamptus*) *balcanicus* s.l. (Kiefer 1933)
*	*Megacyclops viridis* s.l. (Jurine 1820)
**	*Acanthocyclops kieferi* (Chappuis 1925)
**	*Acanthocyclops troglophilus* (Kiefer 1932)
**	*Diacyclops languidoides goticus* (Kiefer 1931)
**	*Diacyclops charon* (Kiefer 1930)
**	*Speocyclops infernus* (Kiefer 1930)
	AMPHIPODA
**T	*Niphargus orcinus* Joseph 1868 [Plate 1:6]
**	*Niphargus wolfi* Schellenberg 1933
**T	*Niphargus stygius valvasori* S. Karaman 1952 [Plate 1:4]
*	*Synurella ambulans* F. Müller 1846

	TERRESTRIAL
	GASTROPODA
**	*Zospeum kusceri* A.J. Wagner 1912
**	*Zospeum isselianum* Pollonera 1886
	PSEUDOSCORPIONES
**	*Neobisium* (*Blothrus*) *spelaeum spelaeum* (Schioedte 1848)
**	*Chthonius* (*Globochthonius*) *spelaeophilus spelaeophilus* Hadži 1930
	ARANEAE
**	*Stalita taenaria* Schioedte 1848 [Plate 1:5+7]
**	*Parastalita stygia* (Joseph 1882)
**	*Troglohyphantes excavatus* Fage 1919
	Meta menardi (Latreille 1804)
	Metellina merianae (Scopoli 1763)
	ACARI
	Eugamasus loricatus Wankel 1861
	Schwiebea cavernicola Vitzthum 1932
?	*Ixodes vespertilionis* Koch 1844
	ISOPODA
**	*Titanethes albus* (C. Koch, 1841)
**	*Androniscus stygius tschameri* Strouhal 1935 [Plate 2:5]
	DIPLOPODA
**	*Attemsia falcifera* Verhoeff 1899 (= *Attemsia pretneri* Strasser 1933)
	Brachydesmus sp.
	COLLEMBOLA
J	*Arrhopalites pygmaea* (Wankel 1860) (= *Dicyrtoma* p.)
J	*Sminthurus niveus* Joseph 1882
J	*Sminthurus longicornis* Joseph 1882
J	*Tritomurus scutellatus* Frauenfeld 1854
J	*Dicyrtoma spelaea* n.n.?
J	*Heteromurus albus* n.n.?
?	Collembola gg. spp.
	DIPLURA
**	*Plusiocampa* (*Stygiocampa*) *nivea* (Joseph 1882)
	ORTHOPTERA
	Troglophilus sp.
	COLEOPTERA
**	*Machaerites ravasinii* (J. Mueller 1922)
J	*Atheta spelaea* (Erichson 1840) (? = *Homalota* s.)
**T	*Bathyscimorphus trifurcatus* Jeannel 1924 [Plate 2:4]
**	*Bathysciotes k. khevenhuelleri* (Miller 1852) [Plate 2:3]
**	*Leptodirus h. hochenwartii* Schmidt 1832 [Plate 1:3]

Table 1: List of species recorded from Križna jama. T – Križna jama is the type locality of the taxon; ** – supposedly troglobiotic species; * – troglobiotic population (race).

	AQUATIC		TERRESTRIAL
	ISOPODA	**J	*Aphaobius milleri* (Schmidt 1855) [Plate 2:2]
**T	*Monolistra racovitzai* Strouhal 1928 [Plate 1:2]	J	*Orotrechus globulipennis* (Schaum 1860) = *Anophthalmus globulipennis* Schmidt = *A. longicornis* Motschulsky
		**T	*Typhlotrechus bilimeki frigens* Jeannel 1928 [Plate 2:6]
	PLECOPTERA	**T	*Anophthalmus heteromorphus* (J. Mueller 1923)
	Nemouridae g. sp. – larvae		*Laemostenus elongatus* Dejean 1828
			Laemostenus schreibersii Kuster 1846
			LEPIDOPTERA
			Triphosa dubitata (Linnaeus 1758)
			Scoliopteryx libatrix (Linnaeus 1758)
			DIPTERA
			Phoridae g. sp.
			Trichoceridae g. sp
		J	*Gymnomus troglodytes* Loew 1863
		J	*Nycteribia latreillii* (Leach 1817)
		J	*Nycteribia frauenfeldii* Kolenati
			CHIROPTERA
			Rhinolophus hipposideros (Bechstein 1800) [Plate 2:1]
			Rhinolophus ferrumequinum (Schreber 1774)
			Myotis myotis (Borkhausen 1797)
			Myotis daubentonii (Kuhl 1819)
			Eptesicus serotinus (Schreber 1774)
			Barbastella barbastellus (Schreber 1774)
			Miniopterus schreibersii (Kuhl 1819) [Plate 2:7]

Table 1, continued: List of species recorded from Križna jama. **T** – Križna jama is the type locality of the taxon; ** – supposedly troglobiotic species; * – troglobiotic population (race).

in Križna jama are Balkanic or Dinaric elements, like the species complex *Bryocamptus balcanicus* s.l., *Acanthocyclops troglophilus* and *Diacyclops charon*. *Acanthocyclops kieferi*, *Diacyclops languidoides goticus* (so named from the "Gothic hall" [Gotska dvorana] of Postojna-Planina cave system, its type locality) and *Speocyclops infernus* are troglobionts more widely distributed in Southern Europe. Three strictly endemic harpacticoid copepods are found in Križna jama: *Elaphoidella stammeri* is endemic to Slovenian cave waters, while *Elaphoidella jeanneli* was recently found (unpublished data) in caves of Croatia and in the Carso/Kras in Italy; a new, highly specialized, species of the genus *Lessinocamptus* was recently discovered in the subterranean brook of Glavni rov. Only three described species are known from the Lessinian mountains (Central Pre-Alps in Italy).

Among malacostracans, the eutroglophilous *Synurella ambulans* is very widely distributed in Europe, which includes several slightly troglomorphic and troglobiotic populations-races in Dinarides and elsewhere. Troglomorphic is also the population found in Križna jama (alike the so-called *S. jugoslavica subterranea* S. Karaman 1932). The NW merodinaric elements are represented by *Niphargus orcinus*, while the distribution of *N. stygius* and *Monolistra racovitzai* is limited to western Slovenia and neighbouring parts of NE Italy.

Interesting is the presence of *Sphaeromicola stammeri* and *Stygodyticola hadzii*, epizoans or exterior parasites hosted by the crustaceans of the genus *Monolistra* and *Niphargus* respectively. *Stygodyticola hadzii* is a holodinaric element (sensu Sket & Zagmajster, 2006), present on niphargid amphipods also in Hercegovina.

Also the terrestrial fauna is biogeographically diversified. *Zospeum kusceri* was found scattered over Slovenia, *Z. isselianum* inhabits all karst regions in Slovenia, i.e. the Dinaric, Alpine and isolated karst. All beetles are members either of Dinaric-Alpine (*Anophthalmus*, *Orotrechus*) or of NW-merodinaric genera (*Aphaobius*, *Typhlotrechus*) while their local species are endemic to SW Slovenia or have a narrower distribution area. *Machaerites ravasinii*, *Bathyscimorphus trifurcatus*, *Bathysciotes khevenhuelleri* are SW Slovenian, such are also the spider *Stalita taenaria* and the pseudoscorpion *Neobisium spelaeum*; except for *B. trifurcatus*, they are present in NE Italy as well. *Anophthalmus heteromorphus* seems to be endemic to the Križna jama area. NW merodinaric are also the trichoniscid woodlouse genus *Titanethes*, the beetle species *Leptodirus hochenwartii* and its entire genus, and the spider *Parastalita stygia*.

4. Acknowledgements

Some colleagues are thanked for turning our attention to the literature we missed or for kindly providing us with their own data: F. Gasparo for different invertebrates, B. Sambugar for Oligochaeta and M. Zagmajster for bats.

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PLATE 1

Fig. 1 *Delaya bureschi*

Fig. 2 *Monolistra racovitzai*

Fig. 3 *Leptodirus hochenwartii*

Fig. 4 *Niphargus stygius*

Fig. 5 *Stalita taenaria*, detail

Fig. 6 *Niphargus orcinus*

Fig. 7 *Stalita taenaria*

Not to scale.

PLATE 1

PLATE 2

Fig. 1 *Rhinolophus hipposideros*

Fig. 2 *Aphaobius* sp.

Fig. 3 *Bathysciotes* sp.

Fig. 4 *Bathyscimorphus* sp.

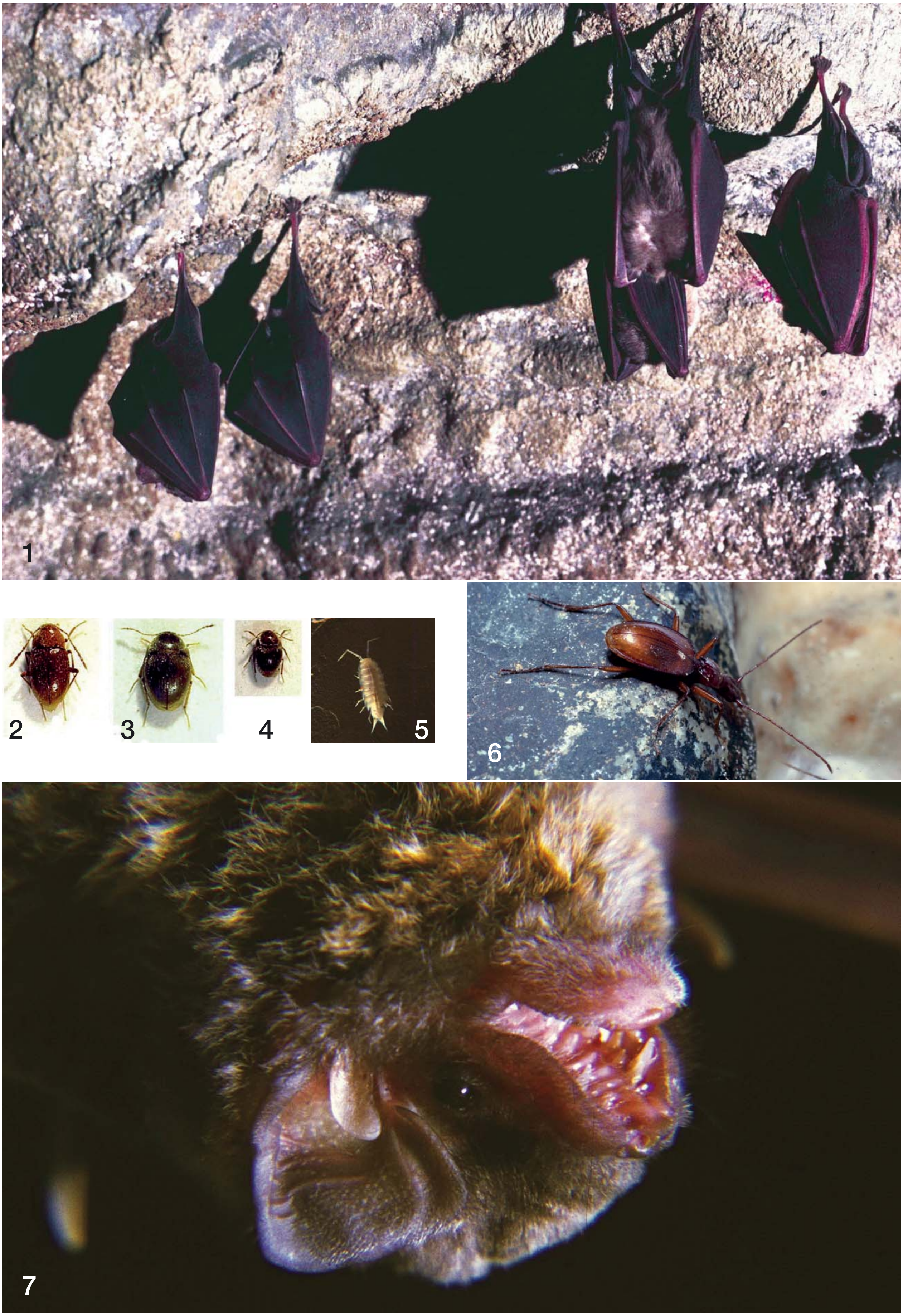
Fig. 5 *Titanethes albus*

Fig. 6 *Typhlotrechus bilimeki*

Fig. 7 *Miniopterus schreibersii*

Not to scale.

PLATE 2



Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:57 – 63, Wien 2014

Metrics and Evolutionary Level of Teeth of the Bears from Križna jama (Slovenia)

by

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Rabeder, G., 2014. Metrics and Evolutionary Level of Teeth of the Bears from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:57 – 63, Wien.

Zusammenfassung

Die metrische Analyse von 44 messbaren Eckzähnen ergab, dass die Križna jama vorwiegend von männlichen Bären als Winterquartier benutzt worden ist - zumindest im Bereich der so genannten "Kittl's Bärenhöhle", aus der das untersuchte Material hauptsächlich stammt.
Die metrische und morphologische Aufnahme von 212 Backenzähnen lässt den Schluss zu, dass die Bären der Križna jama der Art *Ursus ingressus* angehören. Das ergibt sich aus den relativ großen Dimensionen und dem hohen morphodynamischen Niveau der 4. Prämolaren und der Molaren M_1, M_2 und M^2.

Summary

Metrical analysis of the 44 measurable canine teeth and its results show, that Križna jama was used by male bears as a winter-ground, at least in the area of the so called "Kittl's Bear-cave" from where the analysed material mainly comes from.
The metrical and morphological uptake of 212 molars comes to the conclusion that the bears of Križna jama belong to the species *Ursus ingressus*. This follows from the relative large dimensions and a high morphodynamic level of the 4th premolars and the molars M_1, M_2 and M^2.

Izvleček

Izsledki raziskav 44 medvedjih podočnikov (kaninov) so pokazali, da so pretežno samci prezimovali v Križni jami. Predvsem velja to za »Kittlovo medvedjo jamo«, od koder izhaja večina preiskanih zob. Meritve in morfološka analiza 212 kočnikov (molarjev) je pokazala, da pripadajo medvedi iz Križne jame vrsti *Ursus ingressus*. Dokaz za to so relativno veliki zobje in visok morfodinamičen nivo 4. Predmeljaka (premolarja) in treh meljakov (molarjev) – M_1, M_2 in M^2.

1. Material

All teeth and jaws dealt with herein were unearthed during the excavation campaign from 1999 and 2001. The huge amount of skulls and lower jaws from the old excavations performed by Ferdinand von Hochstetter, formerly housed in the Museum of Natural History in Vienna, disappeared and cannot be included in this analysis. The following numbers of teeth suitable for measuring were used, see Table 1:

Category	Permanent
Canini *)	44
P^4	28
M^1	31
M^2	32
P_4	30
M_1	31
M_2	27
M_3	33

Table 1: List of measurable canines and cheek teeth from Križna jama (Slovenia). *) Due to the fact that it was impossible to distinguish between upper and lower jaw in every single case the canines were treated together.

2. Dimensional Comparison

The comparison in size with other cave bears from alpine regions and also from the lowlands shows that the bear from Križna jama is one of the biggest bears. When

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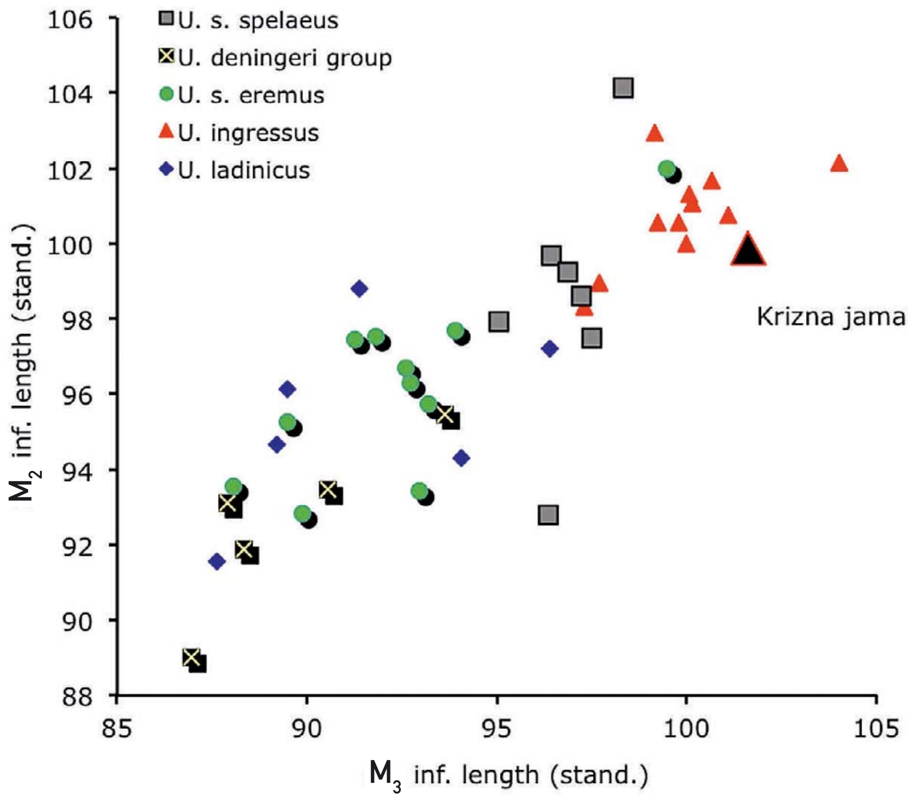

Figure 1: Comparison of size of molars of Pleistocene cave bear faunas in Europe.

comparing the averaged lengths of M^2 and M_3 the bears from Križna jama supersede most of the other cave bears, see Figure 1. The distribution of length and width of all teeth shows congruence with the bears from Gamssulzen cave, Herdengel cave (layer 5–6), Hartelsgraben cave, Drachenhöhle von Mixnitz, Merkenstein cave, Nixloch, Lieglloch, (Austria), from Mokriška jama and Potočka zijalka (Slovenia) as well as with the big sized cave bears from Germany (Zoolithenhöhle, Erpfingen, Hohle Stein) and Spain (Ekaïn, Arrikrutz, Toll and Reguerillo). All the other cave bear faunas are attributable to the *U. deningeri*-group (Hundsheim, Jagsthausen, Petershöhle, Hunas, Repolusthöhle and Herkova jama), to *U. ladinicus* (Conturines cave, Brieglersberg cave, Sulzfluh cave, Ajdovska jama, Grotte de Prélétang and Grotte de Merveilleuse) and to *U. eremus* (Ramesch-Knochenhöhle, Salzofen cave, Ochsenhalt cave, Schwabenreith cave und Herdengelcave (layer 3) show by far smaller dimensions of the molars, with only one exception: the bears from Grotta di Pocalà (Calligaris et al., 2005) which come close to the bears from Križna jama but genetically belong to *U. eremus*.
Data from: Calligaris et al. (2005), Pacher et al. (2004, 2011), Rabeder (1995, 1999), Rabeder et al. (2008), Torres (1988) and original.

Sexual dimorphism: Based on the distribution of size, the canines form two distinctly separated clusters, which probably represent sexes, see Rabeder & Withalm (this volume: Fig. 2). There are only 11 canines attributable to females contrasting with 34 canines representing the males. Thus the sex index (number of females/total number x 100) is 24.44 and the sex ratio (number of females/number of males) equals 0.32. The cave bear fauna from Križna jama was – at least in Kittl's Bärenhöhle – dominated by males, only one quarter of the analysed canines was probably female. A similar distributional pattern with a male domination is observable in the cave bear fauna from Potocka zijalka, the only difference is that the separation is not so strict as in Križna jama, see Pacher et al. (2004).
A totally different relation of sexes can be observed in Gamssulzenhöhle: females dominate this fauna, for comparisons see Rabeder (1995). Moreover, within the male canines from Gamssulzenhöhle the really big teeth with a width wider than 23 mm are missing. This results in a much bigger variability in the bears from Križna jama when comparing to the two other sites. By means of comparison of these three cave bear faunas a possible explanation for the sex ratio of Potocka bears was found, see Table 2.

3. Morphodynamic Analysis

P^3
No P^3-alveolus could be found in the 13 upper jaws or upper jaw fragments respectively.

Morphotypes of the P^4
The distribution of P^4-morphotypes within the Križna material is shown in Table 3. Due to the fact that most of the P^4 (95%) show a fully developed metaloph the resulting index is high. Approximately 60% show also a protoloph. The number of usable teeth is reduced because 38% of all fourth upper premolars are too heavily worn. This limits also the worth of the analysis itself.

Table 2: Analysis of canines from three different bear caves.

			Range of canine width (mm)		
	Sex index (%)	Sex ratio	Male	Total	n
Potočka zijalka	25.40	0.34	4.8	8.9	63
Križna jama	24.44	0.32	5.5	10	45
Gamssulzenhöhle	73.50	2.70	4.2	8.9	83

Morphotype	f_i	Metaconulus	Metaloph	Protostyle	Protoloph	w_i	$f_i \cdot w_i$
A/D	1	0	1	0	0	1	1.00
B/D	1	1	0.5	0	0	1.5	1.50
D	5	1	1	0	0	2	10.00
D/F	6	1	1	0	1	3	18.00
E	1	1	1	1	0	3	3.00
E/F	1	1	1	1	0.5	3.5	3.50
E/F-F	1	1	1	1	0.75	3.75	3.75
F	3	1	1	1	1	4	12.00
n	19					$\Sigma (f_i.w_i)$	52.75

P^4-index = $\Sigma (f_i.w_i) \times 100/n$ = 277.63. Index standardized = 108.5 (GS standard = 255.7)

Table 3: Weighting of P^4 morphotypes and calculation of morphodynamic indices. **f** – (frequency) number of morphotypes, **w** – (worth) morphodynamic factor = sum of single valued steps, GS standard = P^4-index of Gamssulzen cave (see Rabeder, 1995; 1999).

Morphotype	f_i	Paraconid	Metaconid	Metastylids	Hypoconid	Metalophid	Hypolophid	w_i	$f_i \cdot w_i$
B/C1	2	0.5	0.25	0	0	0	0	0.75	1.50
C1	4	0.5	0.5	0	0	0	0	1	4.00
C1/2	3	0.5	0.5	0	0.5	0	0	1.5	4.50
C1-C1/2	1	0.5	0.5	0	0.25	0	0	1.25	1.25
C1-E1	3	0.5	0.5	0	0	0.5	0	1.5	4.50
C1-E1/2	2	0.5	0.5	0	0.5	0.25	0	1.75	3.50
C2	4	0.5	0.5	0	1	0	0	2	8.00
D1	3	0.5	0.5	0.5	0	0	0	1.5	4.50
D1/2	1	0.5	0.5	0.5	0.5	0	0	2	2.00
D2	2	0.5	0.5	0.5	1	0	0	2.5	5.00
D2/F2	1	0.5	0.5	0.5	1	0	1	3.5	3.50
E1	2	0.5	0.5	0.5	0	0.5	0	2	4.00
E1/2	2	0.5	0.5	0.5	0.5	0.5	0	2.5	5.00
n	30							$\Sigma(f_i.w_i)$	51.25

P_4-index = $\Sigma (f_i.w_i) \times 100/n$ = 170.83. Index standardized = 86.19 (GS standard = 198.2)

Table 4: Weighting of P_4 morphotypes and calculation of morphodynamic indices. **f** – (frequency) number of morphotypes, **w** – (worth) morphodynamic factor = sum of single valued steps, GS standard = P_4-index of Gamssulzen cave (see Rabeder, 1995; 1999).

Morphotypes of the P_4

The distribution of P_4-morphotypes within the Križna material is shown in Table 4. The following pattern is applied for the taxation of additional occlusal(?) elements: Elements of the Trigonid like fully developed cuspids and lophids (paraconid, metaconid, metastylid and metalophid) equal a factor of 0.5, the elements of the talonid equal a factor of 1. An explanation for the comparably high index of the p4 from Križna jama can be found in a lack of the primitive morphotypes A and B1 as well as in the presence of a hypoconid in approximately 25% of the teeth. Traces of a metalophid are visible in 27%, and some are even fully developed whereas a hypolophid is seldom. All in all there is a domination of the highly developed morphotypes.

The P4/4-index: The P4/4-index is the geometric mean of P^4- and P_4-index and is calculated in the following way:

P4/4-index (geometric mean of 277.63 and 170.83) = 217.78. Standardised = 96.74

Morphotypes of the M^2: The most obvious evolutionary change concerns the occlusal surface of the M^2 – the development of the metaloph, i.e. the connection of the metacone and the inner ridge with a row of cusps or even by a single edge. This metaloph corresponds to the distal margin of the M_2. Also within the material from Križna jama there is a variation of this character from morphotype A (unordered) and B (misarranged) to morphotype C (strictly ordered). Morphotype D (a single edge) was not found at all. The numbers from 1 to 3 characterize the position of the metaloph; 1 – the row is situated between meta- and hypocone, 3 – between meta- and protocone and 2 is somewhere in between. The curvature of the metaloph towards mesiolingual is interpreted as an adaptation to the form of the distal M_2. Within the material from Križna jama there is a domination of morphotype C3 (< 60%), on the other hand there are also three samples without an ordered metaloph (morphotype A). An explanation for the high M^2-metaloph index of the Križna jama bears can be found in the high abundance of

Morphotype	f_i	Cusp row	Course of cusp row	w_i	$f_i \cdot w_i$
A	3	unordered	No course at all	1	3
B1	3	misarranged	Towards hypocone	2	6
B2	2	misarranged	Towards a point between proto- and hypocone	3	6
B3	1	misarranged	Towards a point between proto- and hypocone	4	4
C1	2	strictly ordered	Towards protocone	3	6
C2	1	strictly ordered	Towards a point between proto- and hypocone	4	4
C3	13	strictly ordered	Towards protocone	5	65
D3	0	cutting ridge	to protocone	6	0

M^2-metaloph index = $\Sigma (f_i.w_i) \times 100/n$ = 376.00. Index standardized = 100.27 (GS standard = 375.0)

Table 5: Weighting of metaloph morphotypes of M^2 and calculation of morphodynamic indices. f – (frequency) number of morphotypes, w – (worth) morphodynamic factor = sum of single valued steps, GS standard = M^2-metaloph index of Gamssulzen cave (see Rabeder, 1999).

Posteroloph morphotype	f_i	Cusp row between metastyle and hypocone	w_i	$f_i \cdot w_i$
0	0	No cusps	0	0
1	0	With cusps, not transversally ordered	1	0
1/2	1	Cusps partially ordered transversal	1.5	1.5
2	5	Cusp row misarranged or imperfect	2	6
2/3	1	Transversal cusp row not complete	2.5	2.5
3	13	Cusp row complete	3	39
n	18		$\Sigma (f_i.w_i)$	49

Table 6: Weighting of posteroloph morphotypes of M^2 and calculation of morphodynamic indices. **f** – (frequency) number of morphotypes, **w** – (worth) morphodynamic factor = sum of single valued steps, GS standard = M^2 posteroloph index of Gamssulzen cave (see Rabeder, 1999).

M^2-posteroloph index = $\Sigma (f_i.w_i) \times 100/n$ = 265.00. Index standardized = 126.79 (GS standard = 209.0)

Table 7: Weighting of M_1 and M_2 enthypoconid morphotypes and calculation of morphodynamic indices. **f** – (frequency) number of morphotypes, **w** – (worth) morphodynamic factor = sum of single valued steps, GS standard = m1 resp. M_2 enthypoconid index of Gamssulzen cave (see Rabeder, 1999).

Enthypoconid morphotype	fi		Enthypoconid consists of	w_i	fi . wi	
	M_1	M_2			M_1	M_2
A	0	0	No cusps	0.0	0	0
B	6	0	1 cusp	0.5	6	0
B/C	2	6	1 cusp and a second imperfect one	1.0	3	9
C	0	3	2 cusps	1.5	0	6
C/D	3	2	2 cusps and a third imperfect one	2.0	7.5	5
D	0	0	3 cusps	2.5	0	0
n	**11**	**11**		**3.0**	**16.5**	**20**

M_1 index = Σ (fi.wi).100/n = 150.00. Index standardized = 114.50 (GS standard = 131.0)
M_2 index = Σ (fi.wi).100/n = 181.82. Index standardized = 98.12 (GS standard = 185.3)

	mean	GS standard	standardised	deviation	max	min	number
female canines length	22.09	21.13		—	24.0	20.6	11
female canines width	15.72	15.36	102.33	—	16.5	14.0	11
male canines length	28.27	26.45	106.87	2.73	34.3	22.7	33
male canines width	21.46	19.63	109.33	1.43	24.0	18.5	33
P^4 length	20.03	20.13	99.49	1.43	22.2	17.3	28
P^4 width	14.27	14.21	100.39	1.04	16.6	12.1	2
P^4 Index	276.39	255.70	108.09	—	4.0	1.5	18
P4/4 index	217.75	225.12	96.72				
P_4 length	15.42	15.24	101.18	0.99	17.3	13.9	30
P_4 width	10.69	10.32	103.62	0.82	12.3	9.4	30
P_4 index	175.83	198.20	88.72	—	3.0	0.75	30
M^1 length	28.57	28.73	99.38	1.12	32.0	26.7	31
M^1 Width	19.93	19.75	100.76	1.14	22.5	18.0	31
M^2 length	46.00	44.40	103.61	2.97	50.4	39.9	32
M^2 Width	23.20	22.55	102.90	1.12	25.4	21.1	32
M^2 metaloph index	400.00	375.00	106.67	—	6.0	1.0	22
M^2 posteroloph index	265.00	209.00	126.79		3.0	1.0	18
M_1 length	30.47	30.22	100.82	1.26	33.0	27.5	31
M_1 width	15.33	14.50	105.72	1.14	19.3	13.8	31
M_1 enthypoconid index	140.91	131.00	107.56	—	2.5	1.0	11
M_2 length	30.56	30.63	99.88	1.44	33.6	27.6	31
M_2 width	18.86	18.25	103.32	1.17	21.1	17.0	29
M_2 enthypoconid index	192.00	185.3	103.44	—	2.5	1.5	12
M_3 length	28.01	27.56	101.63	2.05	30.7	22.4	33
M_3 width	19.93	19.11	104.28	1.29	21.6	15.5	33
M^2/M^1 length ratio	161.04	154.54	104.26				
M_3/M_2 length ratio	91.56	89.98	101.75				

Table 8: Measurements of canines and cheek teeth of *Ursus ingressus* from Križna jama (Slovenia).

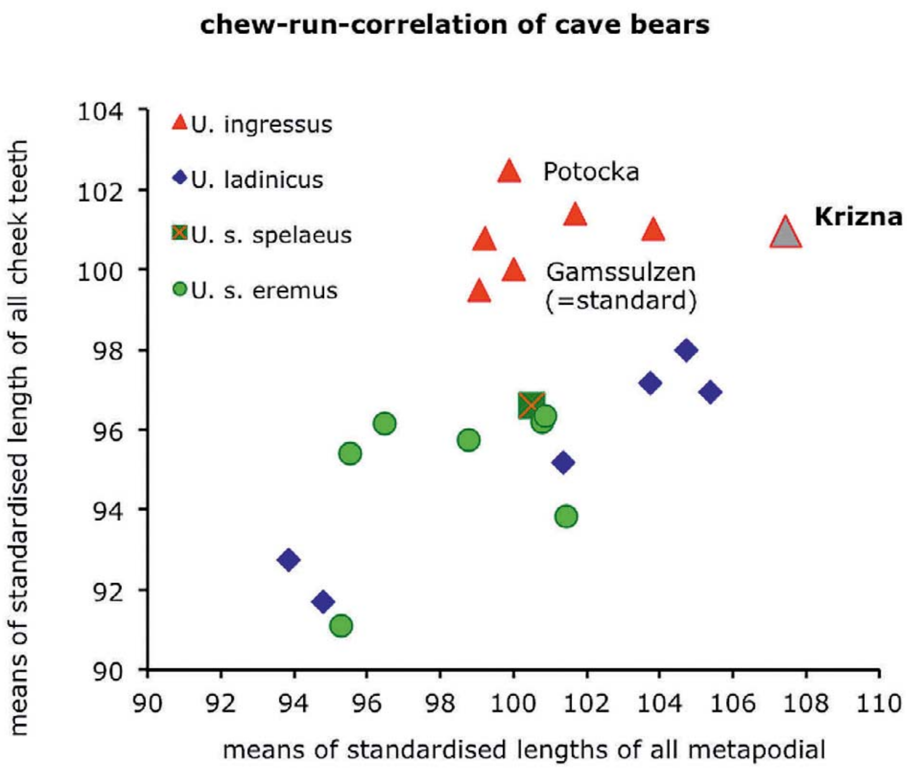

Figure 2: Correlation between length of metapodial bones and length of cheek teeth of the cave bear faunas (compare to Rabeder & Withalm, 2011:diagram 2–3)

morphotype C3. A second row of little accessory cusps is situated distally to the metaloph, reaching from metastyle to the hypocone. It is called posteroloph. Within the material from Križna jama there are only 18 teeth showing this character, but these teeth show an exceptionally high-developed posteroloph. 13 upper M^2 from Križna jama show the highest developmental level which is called morphotype "3" and counts three. A not so well ordered or incomplete row of cusps is called morphotype "2" and was found only three times in Križna jama. Last but not least there are two more teeth with an intermediate developmental level between morphotype "1", which shows cusps that are not transversally ordered, and "2" and "2" and "3" respectively. The M^2-metaloph index is given in Table 5, the M^2-posteroloph index is given in Table 6.

Functional Analysis: An explanation for the function of meta- and posteroloph can be found in their position in respect of the molars of the lower jaw as well as by the abrasional patterns. The M^2-metaloph fits perfectly well in the incision between M_2 and M_3 and follows the distal margin of the M_2, the latter runs with several cusps from hypoconid to the entoconid. The posteroloph functions as an antagonist of the highly variable structure of the M_3-protoconid.

4. The Enthypoconid-Index of M_1 and M_2

The formation of the enthypoconid can be explained as an adaptation to the pressure of mastication and the related abrasion of the M^1 paracone and the M^2 paracone as well. It is calculated by the number of cusps the enthypoconid consists of and proved to be a good tool because it helps to distinguish between the different evolutionary lines of cave bears. The number of usable M_1 and M_2 is pitifully low as most of the teeth are heavily worn, but the few usable teeth show a high evolutionary level which is comparable to those of the bears from Gamssulzen cave, see Table 7.

5. Conclusion

The metric values of the studied teeth, see Table 8, lay with few exceptions (length of P^4, M^1 and M_2) above the volumes of standard fauna of *Ursus ingressus* Rabeder et al., 2004 from the Gamssulzen cave (Rabeder, 1995, 1999). The „mean of standardised length of all cheek teeth" is a significant index for the discrimination of cave bear species (see Rabeder & Withalm, 2011:75–76:diagram 2 and 3). The cluster of *Ursus ingressus* is defined specially with high means of cheek teeth measurements. The means of standardised values (length: 100.86, width: 103.00) of Križna jama are the greatest ones of all cave bears (see Fig. 1).

In the „chew-run-diagram" the mean of all standardised lengths of cheek teeth are related to the mean of all standardised length of metapodial bones. The fauna of Križna jama falls clearly in the cluster of *Ursus ingressus* (see Fig. 2).

The most values of all important morphodynamic indices (P^4 index, enthypoconid index of M_1 and M_2, metaloph index and posteroloph index of M^2, M^2/M^1 index and M_3/M_2 index) are higher than the Gamssulzen values with one exception: the P_4 index fits under the Gamssulzen level. The high values of morphodynamic indices argue for a affilation to *Ursus ingressus* also.

6. References

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Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:65 – 74, Wien 2014

The Study of Cave Bear Milk Teeth from Križna Jama Cave, Slovenia

by

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Pappa, S., 2014. The Study of Cave Bear Milk Teeth from Križna Jama Cave, Slovenia. — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:65 – 74, Wien.

Zusammenfassung

Im Zuge systematischer Untersuchungen an quartären Höhlenfaunen wird gezeigt, dass diejenigen der Križna jama und Herkova jama im Hinblick auf Höhlenbärenmilchzähnen von besonderem Interesse sind. In dieser Studie werden die Milchzähne der ersteren Höhle beschrieben und diskutiert. Sowohl die Analyse der Morphotypen als auch die der morphodynamischen Indices und ihrer Kauflächenmuster scheint bei den oberen und unteren Milchprämolaren – so wie auch bereits bei den P4 (Rabeder, 1983) – die Evolution des jungpleistozänen *Ursus ingressus* aus Slowenien zu quantifizieren.
Schlüsselwörter: *Ursus ingressus*, morphodynamische Analyse, Morphotypen, morphodynamische Indices

Izvleček

V teku sistematskih raziskav kvartarnega jamskega živalstva se je pokazalo, da sta Križna jama in Jama pod Herkovimi pečmi paleontološko posebno zanimivi spričo mlečnih zob jamskih medvedov. V tem sestavku smo opisali in razpravljali o mlečnih zobeh iz prve jame. Kot analiza morfotipov in morfodinamičnih indeksov bi lahko tudi vzorci žvekalne površine zgornjih in spodnjih mlečnih premolarjev dali več podatkov o razvoju mlajše pleistocenske vrste *Ursus ingressus* v Sloveniji – podobno kot pri P4 (Rabeder, 1983).
Ključne besede: *Ursus ingressus*, morfodinamična analiza, morfotipi, morfodinamični indeksi

Abstract

From systematic studies on Quaternary cave faunas in Slovenia, it is shown that two caves, Križna jama and Herkova jama are of palaeontological interest concerning the cave bear milk teeth. In this study the deciduous teeth from the former cave are described and discussed. The morphotypes that are also analyzed, as well as the morphodynamic indices and their patterns from the upper and lower fourth deciduous carnassials teeth, may quantify the cave bear evolution of the Late Pleistocene *Ursus ingressus* from Slovenia as it happed on P4 (Rabeder, 1983).
Keywords: *Ursus ingressus*, morphodynamic analysis, morphotypes, morphodynamic indices

1. Introduction & Methodology

The research and excavations in Križna jama (Ljubljana) were carried out by the Institute of Paleontology, University of Vienna in cooperation with Ljubljana University from 2000 until 2002. The material studied here is stored in the Institute of Paleontology, University of Vienna, while a few specimens are stored in the Natural History Museum of Vienna.
The chronology of deciduous teeth from Križna jama is based on dating and morphometric analyses of permanent teeth and adult post cranial material of *Ursus ingressus*, and gives an age of 34,000 to 32,000 kya. (Pohar et al., 2002; Rabeder et al., 2008).
Nordmann was the first person to study the bear milk teeth in 1858, followed by Schlosser in 1909, Kormos in 1916, Pohle in 1923, Ehrenberg in 1931, Friant & Stehlin in 1933, Mottl in 1934, 1939, Zapfe in 1946; Koby (1952), Erdbrink (1953), Radulescu & Samson (1959), Ehrenberg (1964), Kurten (1968), Terzea (1969), Torres (1988), Andrews & Turner (1992), Debeljak, (1996, 1997).
The cave bear deciduous teeth from Križna jama are described, measured, occlusally figured, discussed and compared with other materials such as the very rich

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milk teeth material from the Almopia Speleopark Bear Cave (Macedonia, Greece), as well as from Herkova jama (Slovenia), from Gamssulzen Höhle (Rabeder, 1999) and from Ochsenhalt Höhle (Austria). In addition, they have been attributed into categories according to Kurten (1976), Pappa et al. (2005), Tsoukala et al. (2006) and Pappa (2010). The four categories of development can be described as follows: A) enamel cap of tooth still concealed in the jaw, root beginning to form, B) unworn tooth with fully formed root, C) tooth with root showing resorption marks and D) shed milk tooth with resorbed root.

The aim of this study is also to apply the morphodynamic analysis and find the morphotypes of the fourth deciduous carnassials. Therefore morphodynamic indices results suggest that some cusps of the occlusal surface on deciduous carnassials are significantly important for understanding the progress of D4 teeth, which may show the evolutionary relationships between the Pleistocene bear species *Ursus ingressus*, *Ursus eremus*, *Ursus ladinicus* and *Ursus deningeri* (Pappa, 2010). Morphological terms follow Rabeder (1999) and measurements have been made according to Tsoukala & Grandal d'Anglade (2002). Morphotype drawings were made with a Karl Zeiss/Jena binocular microscope with camera Lucida in the Palaeontological Institute of Vienna and measurements were taken with dial calipers to mm.

2. Palaeontology & Taxonomy

Order: Carnivora Bowdich, 1821
Suborder: Caniformia Kretzoi, 1943 /
Infraorder Arctoidea Flower, 1869
Family: Ursidae Fischer von Waldheim, 1817

Genus: *Ursus* Linnaeus, 1758

***Ursus ingressus* Rabeder et al., 2004**

Material: 4 dI^3: Kj 185a, 54, 114c sin and Kj 114b dex, **D^3**: Kj 51e sin, **6 D^4**: Kj 51f, 121b, 143b, 143c, 8 sin and Kj 121c dex, **4 dI$_3$**: Kj 52e, 52g sin and Kj 168b, 52f dex, **5 D$_4$**: Kj 185b, 51g, 54a, 62 sin and Kj 145 dex, finally **46 dC**.

Description: From the cave bear material of Křižna jama, 67 milk teeth were studied, drawn and measured here (Table 1), since no complete maxillas and mandibles from juveniles have been found. Most of the milk teeth are deciduous canines.

dI^3: The third milk incisors are the strongest teeth of the milk incisors (Fig. 1). The dI^3 is of similar morphology to the milk canine except for the shorter and more curved crown and the intense palatinal cingulum. The third upper milk incisor Kj 185a is slightly worn and most of the root is preserved and shows resorption marks. The dI^3 Kj 114b and Kj 54 are also slightly worn and their roots have been completely dissolved. The dI^3 Kj 114c is a germ enamel cap. In table 1 shows the measurements.

D^3: The third upper milk premolar Kj 51e (sin) has a pyramid-shaped crown and has slight to medium wear with well-developed talon and two roots that are widely bifurcated but broken (Fig. 2). The mesial root is thinner than the distal root. In table 1 shows the measurements.

dI$_3$: The third milk incisor is the largest lower milk incisor with the crown of triangular shape and a well developed root. There are two to three lingual accessory cuspids, which sometimes form a crest (Fig. 3, Kj 52e; Kj 52f). Three categories of development can be distinguished: the Kj 168b is slightly worn with fully formed root but broken (category B); both the dI$_3$ Kj 52g and Kj 52e with root showing resorption marks (Fig. 3) (category C); and Kj 52f with completely dissolved root from osteoclasts (category D). In table 1 shows the measurements.

dC: The milk canines are the most abundant milk teeth among the Křižna jama material. They are long, flattened and relatively large teeth. It is difficult to distinguish between upper and lower ones, thus both are described here together (Fig. 4). Concerning their wear stage they can be attributed to the categories shown in Table 2: (A) by few

Figure 1: *Ursus ingressus* Křižna jama. Third upper milk incisor.

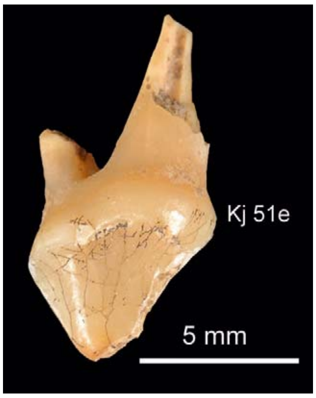

Figure 2: *Ursus ingressus* Križna jama. Third upper milk premolar (lingual side).

Figure 3: *Ursus ingressus* Križna jama. Third lower milk incisors (lingual side).

germs – milk canines consisting of an enamel cap and a root that has barely started to form, (B) by few complete milk canines with unworn occlusal surfaces and where some root development has taken place. In the wear stage (C) the root of the tooth is fully formed, but the crown has no wear, while in (D) the wear stage of the occlusal surface is slight to moderate. Finally, the last stage (E) presents heavily worn occlusal surface.

Regarding the categories of development, four were observed. The first one (A: root beginning to form) with 8 specimens (Fig. 4a) (Kj 51d), the second (B: with fully formed root) with 4 specimens (Fig. 4b) (Kj 210), the third [C: with complete canines and with root showing resumptions marks, which is a preliminary stage to the tooth being shed and as the root is gradually dissolved by the osteoclasts (Koby, 1952)] with 9 specimens (Fig. 4c) (Kj 118); and finally the fourth (D: with resorbed root) with 22 specimens (Fig. 4d) (Kj 53). In table 1 shows the measurements.

D4: The upper and lower milk carnassials are molar-like and the most important of the milk teeth because they contribute to the morphodynamic analysis (Rabeder, 1983, 1991, 1999).

The D^4 has one palatinal and two labial roots. The occlusal shape is trapezoid and sometimes there is a lingual cuspid-like cingulum (Fig. 5, upper row). The labial margin is almost straight and longer than the lingual margin, which is very convex. The two main labial cusps are elongated mesiodistally and both are much larger than the lingual cusps. The mesial cusp (paracone) is larger than the distal cusp (metacone). A small but well differentiated cusp, the parastyle is well preserved in all specimens from Križna jama (Kj) and arises in front of the paracone. Three out of six specimens (Fig. 6, left; Kj 43; Kj 51; Kj 121c) have, on the lingual side of the metacone, an enamel crest descending toward the centre of the crown. In specimen Kj 51 it merges with another crest that originates from the lingual cusps. In

Figure 4: *Ursus ingressus* (Križna jama). Milk canines. Three categories can be distinguished:

A: Germs (Kj 51d),

B: Full teeth (Kj 210),

C: Showing resumptions marks (Kj 118) and

D: shed canines (Kj 53).

	n	x	min – max	s_{n-1}	v
LdI^3 (Kj185a)		–	6.28	–	–
BdI^3 (Kj185a)		–	4.71	–	–
LdI^3 (Kj114b)		–	6.68	–	–
BdI^3 (Kj114b)		–	5.77	–	–
LdI^3 (Kj114c)		–	6.54	–	–
BdI^3 (Kj114c)		–	5.44	–	–
LdI^3 (Kj54)		–	6.59	–	–
BdI^3 (Kj54)		–	5.35	–	–
L dC	43	7.42	6.52 – 8.49	0.43	5.75
B dC	43	5.31	4.43 – 6.25	0.38	7.14
L D^3 (Kj :51e)	1	6.18	–	–	–
B D^3 (Kj :51e)	1	3.92	–	–	–
L D^4	6	11.19	10.11 – 11.94	0.64	5.72
B D^4	6	7.31	6.81 – 7.74	0.39	5.18
LdI_3 (Kj52e)		–	5.37	–	–
BdI_3 (Kj52e)			3.57	–	–
LdI_3 (Kj168b)		–	4.6	–	–
BdI_3 (Kj168b)		–	3.33	–	–
LdI_3 (Kj52f)		–	5.97	–	–
BdI_3 (Kj52f)		–	4.16	–	–
LdI_3 (Kj52g)		–	5.34	–	–
BdI_3 (Kj52g)		–	3.86	–	–
L D_4	5	12.46	11.13 – 13.86	1.22	9.86
B D_4	5	6.39	5.59 – 7.02	0.51	8.09

Table 1: *Ursus ingressus* Križna jama: Measurements of the milk teeth (in mm). L – length, B – breadth

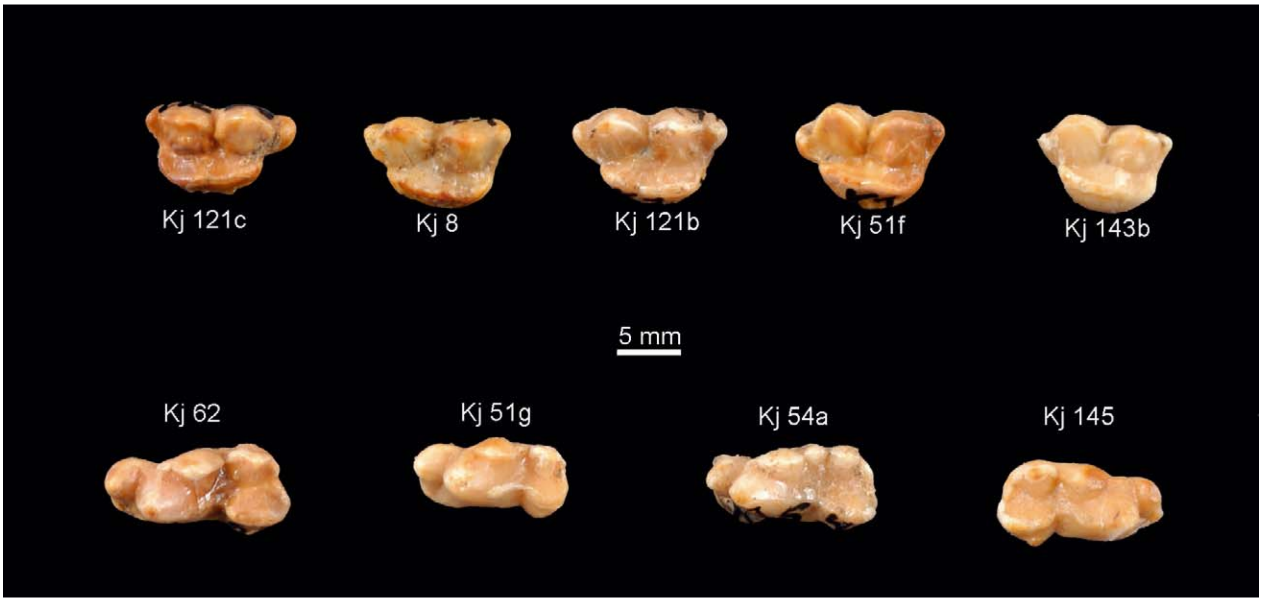

Figure 5: *Ursus ingressus* Križna jama: Material of the milk carnassials showing the variability of their morphotype. Upper row: occlusal views of the upper carnassials D^4, Lower row: occlusal views of the lower carnassials D_4

all specimens the metastyle, which sometimes forms a continuous crest towards the hypocone, originates from next to the metacone. Hypocone is the most important cusp for the morphodynamic analysis. All the D^4 from Križna jama have a hypocone. This cusp is distolingually located on the lingual-distal side of the crown. Additionally, on the lingual margin of the crown there are three to four relatively low cusps which are usually connected with each other by a continuous crest. In some cases the protocone has two apices (Kj 121c). In table 1 shows the measurements.

The D_4 are much more variable than the upper ones, with the crown bearing at least 5 cuspids and two roots. The crown consists of two areas, the talonid and trigonid (Fig. 5, lower row). The trigonid shows three main cusps in all Križna jama specimens, paraconid, protoconid and metaconid. The protoconid is the most conspicuous cusp and separates the paraconid from metaconid as in M_1. From the protoconid, descend three ridges. The first one is on the mesial side towards the paraconid, the second on the distolabial side toward the talonid area and the third on the distolingual side toward the metaconid. In some specimens there is a small lower cusp present between paraconid and metaconid (Fig. 11, right; Kj 62; Kj 51g). Sometimes the paraconid varies in size, for example in Kj 145 (Fig. 11, right) it is small. The discontinuous line in the sample Kj 145 (Fig. 11, right) explains the broken part of the tooth. There are two main cusps on the talonid area, the hypoconid and the entoconid cusps. Usually the hypoconid is larger than the entoconid and is placed on the labial margin. The entoconid is the most important cusp for the morphodynamic analysis of D_4. This cusp varies in number and in size which is a key factor for the final morphodynamic index. In table 1 shows the measurements.

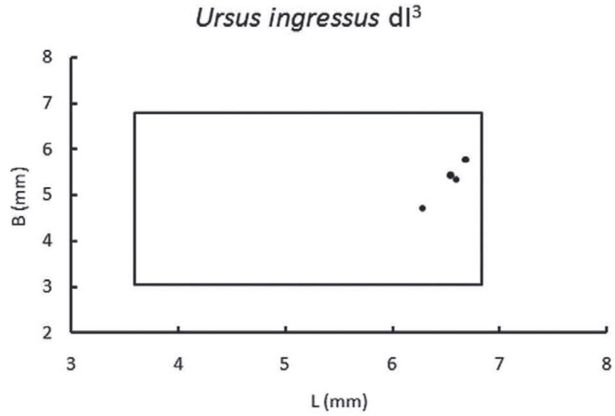

Figure 6: Scatter diagram of L = length and B = breadth of the dI^3 *Ursus ingressus* from Kj and *Ursus arctos* from collections in Moscow (rectangle of a continuous line) (Baryshnikov & Averianov, 1991).

dC Wear stage categories	Description		Križna jama	LAC Pappa et al., 2005	Westbury Andrews & Turner, 1992	Odessa Kurtén, 1976
			Number of specimens			
A	Unerupted	Neonates	7	132	22	13
B	Erupted	Neonates	5	500	10	26
C	Unworn		1	83	32	—
D	Slightly wear	Year-lings	31	130	39	165
E	Heavy wear	Year-lings	—	600	80	—

Table 2: *Ursus ingressus* Križna jama: Wear stages categories of the milk canines in reference with LAC (Loutra Almopias Cave, Greece), Westbury and Odessa localities. Unerupted, when the crown is formed but the root is not; erupting, when some root development has taken place; unworn, when the root is fully formed but the crown has no wear; slight to moderate wear; heavy wear.

Table 3: *Ursus ingressus* Križna jama: Number of specimens from dI^3, D^4 and D_4 (dex) and (sin) showing the MNI (minimum number of individuals).

Teeth	Number of left (sin)	Number of right (dex)
Third milk incisor **dI³**	3	1
Fourth milk premolar of upper jaw **D⁴**	5	1
Fourth milk premolar of lower jaw **D_4**	4	1

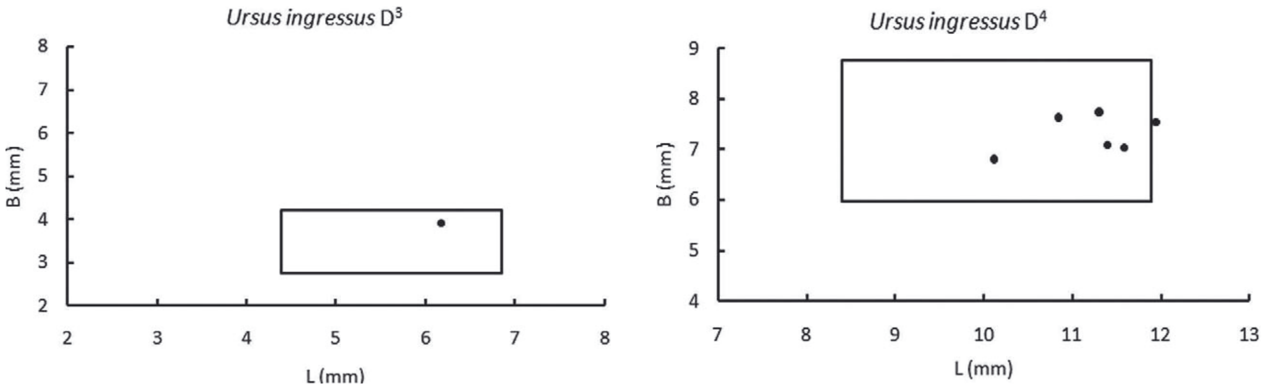

Figure 7: Scatter diagram of L = length and B = breadth of the D^3 (left) and D^4 (right) *Ursus ingressus* from Kj and *Ursus arctos* from collections in Moscow (rectangle of a continuous line) (Baryshnikov & Averianov, 1991).

3. Discussion

The study of the milk teeth can show the presence of unborn bears. Addititionally, however, the completely worn milk teeth show that some specimens belonging to one year old individuals have also been found. In table 2, the wear stage categories of the milk canines from Križna jama are given, in reference with those from various other localities.

By differentiating the number of left and right samples of dI^3, D^4 and D_4 we can find the MNI (minimum number of individuals). Thus the MNI of juvenile individuals is approximately 4 to 5 (table 3).

From the analysis of scatter diagrams of L = length and B = breadth of the upper milk teeth from Kj in comparison with *Ursus arctos*, it is noticeable that there is not a remarkable difference between the measurements (Fig. 6, 7 right and left, 8). However, from the measurements of lower milk teeth from Kj in comparison with *Ursus arctos* it is obvious that in *Ursus ingressus* from Kj the measurements are larger than the lower milk teeth of *Ursus arctos* (Fig. 9 right and left). From the ratio diagram (Fig. 10) it can be seen that there is a similarity in the dimensions between the milk carnassials of *U. ingressus* from Križna jama and Loutra Almopias bear cave, as well as of *U. eremus* from Ochsenhalt. It is also noticeable that the D^4 of *Ursus ingressus* and *Ursus eremus* is smaller in comparison with those of the Middle Pleistocene *U. deningeri* milk carnassials from Herkova jama, while the D_4 is larger.

Morphodynamic Analysis

The milk carnassials D^4 and D_4 are the most important deciduous teeth in the study of morphodynamic analysis of milk teeth and provide evidence for different stages of bear evolution (Rabeder, 1983, 1999; Pappa, 2010). The evaluation of statistic relevant morphological characteristics on selected elements, first only P4, made it possible to quantify the cave bear evolution (Rabeder, 1983). In recent years through radiometric dating methods, there has been a great advance in showing the benefits

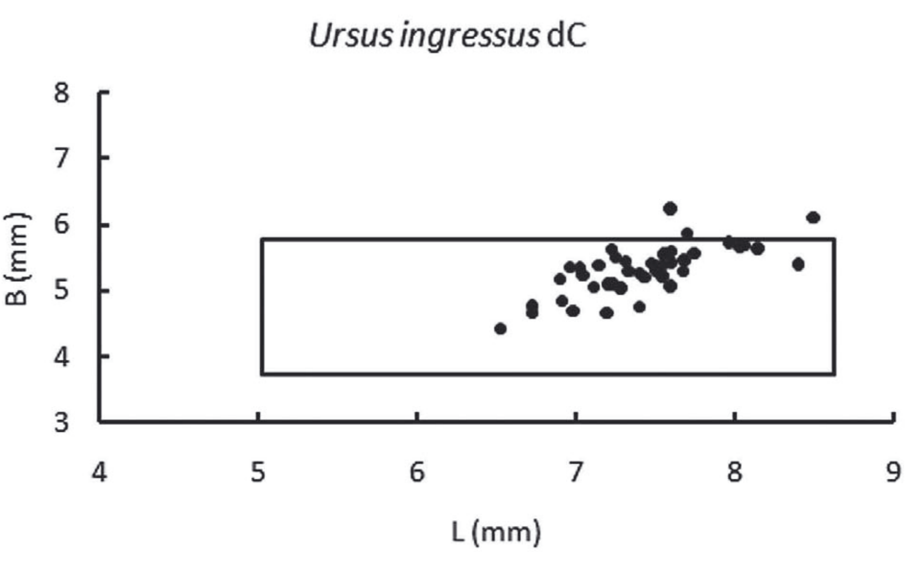

Figure 8: Scatter diagram of L = length and B = breadth of the dC *Ursus ingressus* from Kj and *Ursus arctos* from collections in Moscow (rectangle of a continuous line) (Baryshnikov & Averianov, 1991).

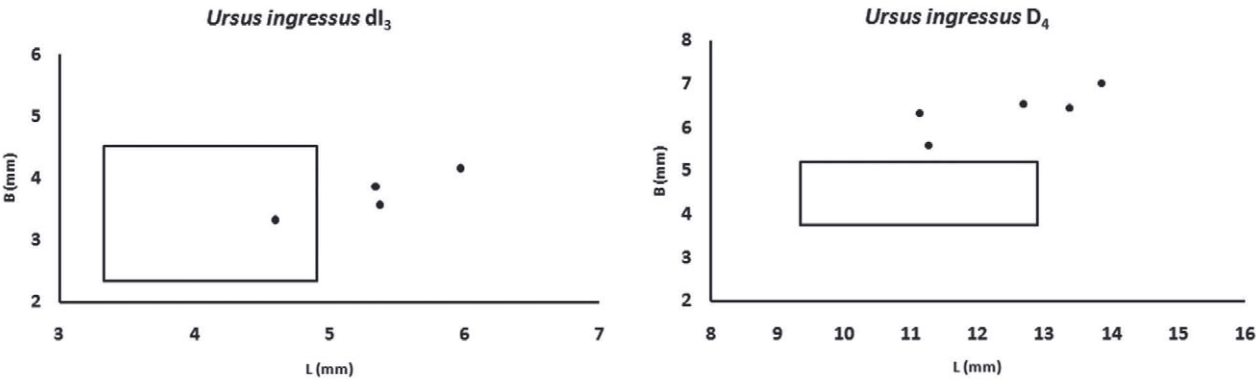

Figure 9: Scatter diagram of L = length and B = breadth of the dI_3 (left) and D_4 (right) *Ursus ingressus* from Kj and *Ursus arctos* from collections in Moscow (rectangle of a continuous line) (Baryshnikov & Averianov, 1991).

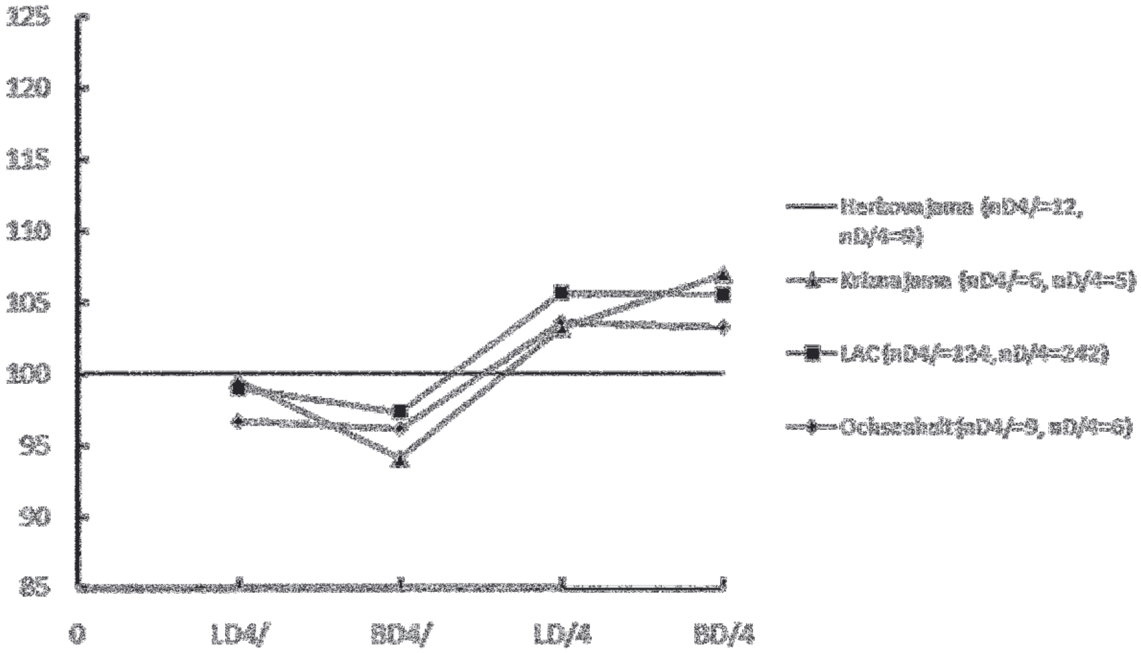

Figure 10: Ratio diagram showing the differences between the standardized Herkova jama: *U. deningeri* (Hj = 100%), comparing the dimensions of the D^4 and D_4 from various sites. Križna jama: *Ursus ingressus*, Loutra Almopias bear cave *Ursus ingressus*, and Ochsenhalt *U. eremus*.

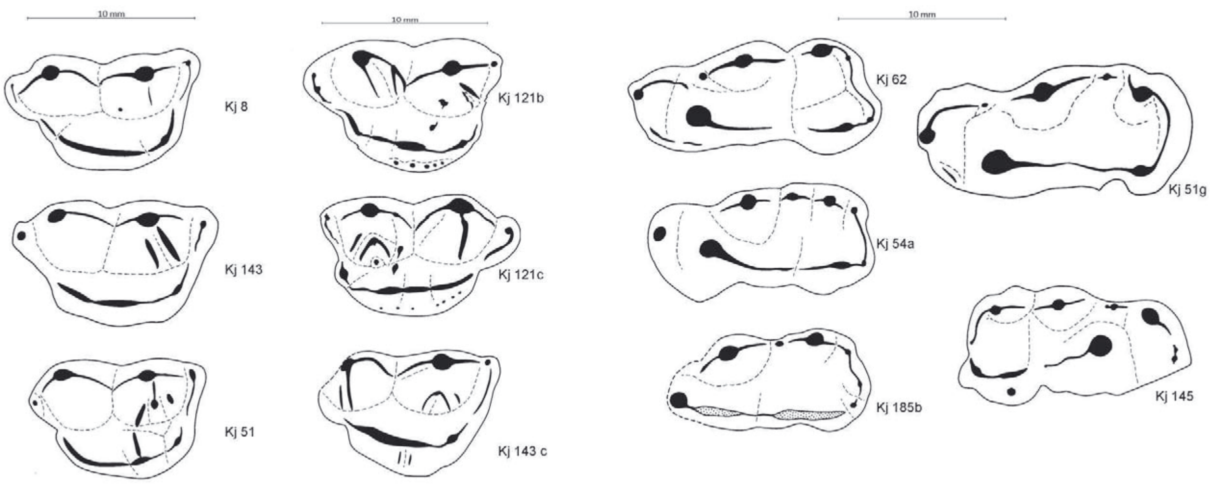

Figure 11: *Ursus ingressus*, Križna jama: morphology of milk carnassials in occlusal views. On the left D^4 and on the right D_4.

Factor	**0**	**1**	**2**		
Morphotype	**A**	**B**	**C**	**n**	**Morphodynamic Indices**
Križna jama *U. ingressus*	1	5	—	6	83
Gamssulzenhöhle *U. ingressus*	3	17	1	21	90.5
Herkova jama *U. deningeri*	7	1	—	8	12.5

Table 4: Categories of morphotypes in milk carnassials D4 and their morphodynamic indices from Križna jama. Compared with morphotypes from Gamssulzenhöhle and Herkova jama (Pappa, 2010).

Factor	**0**	**0.5**	**1**		
Morphotype	**A**	**B**	**C**	**n**	**Morphodynamic Indices**
Križna jama *U. ingressus*	1	4	—	5	40
Gamssulzenhöhle *U. ingressus*	9	11	2	22	34.09
Herkova jama *U. deningeri*	8	1	—	9	5.55

Table 5: Categories of morphotypes in milk carnassials D4 and their morphodynamic indices from Križna jama. Compared with morphotypes from Gamssulzenhöhle and Herkova jama (Pappa, 2010).

of morphodynamic analysis (Rabeder & Nagel, 1997). From the morphology of D^4 we observe that it is similar to M^1. The main difference between these teeth is that in D^4 the distal cusps take up more surface area than the lingual cusps, so the outline of D^4 is of a trapezoid shape in contrast to M^1 which is more quadrate. On D^4 the hypocone is the main cusp (selected element) by which the morphotypes are differentiated. So, the presence or absence of hypocone as well as how robust it is affects the value of the factor assigned to a certain morphotype. With this hypocone reduction, the morphology of D^4 is closer to M^1. From the different figured occlusal views of D^4 we can observe in detail the morphology of the tooth and the size of the hypocone. Following the morphology of occlusal surface of this tooth, the next important step is to find the morphodynamic indices. The index of a population corresponds to the mean of the assessed factors multiplied by 100 (Rabeder & Nagel, 1997; Pappa, 2010).
The morphodynamic analysis of D^4 from Križna jama (Fig. 11, left) shows the presence of two morphotypes, A and B. In morphotype A, the hypocone is very well preserved and is very robust (Kj 121c). While in morphotype B there is a hypocone, but it is not so intense. The morphodynamic index is 83 which is closer to morphodynamic index from Gamssulzenhöhle (Austria, *Ursus ingressus*), than to that from Herkova jama (*Ursus denigeri*), which has more specimens with (A) morphotypes (Table 4).
In lower D_4 from Križna jama (Fig. 11, right), the morphodynamic analysis shows more specimens of the (B) morphotype. In this morphotype there are two entoconids which are different in size, and the distal one is smaller than the mesial one. There is also one specimen in the (A) morphotype category with only one robust entoconid (Fig. 11, right; Kj 62). The morphodynamic index is 40 which is closer to morphodynamic index from Gamssulzenhöhle (Austria, *Ursus ingressus*), than to that from Herkova jama (*Ursus deningeri*) which is 5.55 (Table 5; Pappa, 2010).

4. Conclusions

• In Križna jama the study of the milk teeth shows the presence not only of unborn bears, but also of year old individuals.
• In the development stage of the deciduous canines, it is noticeable that the most abundant category is the last one (D), in which the root of the tooth has been dissolved completely by osteoclasts. Through this it is possible to estimate the approximate individual age of the animals. The ages depend on the deciduous teeth that were examined.
• The analysis of the scatter diagrams of the length and breadth of all deciduous teeth from Križna jama, in comparison with *Ursus arctos*, shows that there are no remarkable differences between the measurements of the teeth of the upper jaw, nor between deciduous canines. However, in the measurements of lower deciduous teeth it is obvious that *Ursus ingressus* from Križna jama has a larger size than the lower milk teeth of *Ursus arctos*.
• The most important deciduous teeth for applying the morphodynamic analysis are the D4 of the upper and lower jaws.
• Due to corresponding evidence of morphotypes and morphodynamic indices in Križna jama, the main cri-

terion for the identification of morphotypes in D^4 is the hypocone and in D_4 it is the entoconid. The final morphodynamic indices of the Križna jama deciduous teeth are 83% for the D^4 and 40% for the D_4.

• The morphotype of the milk carnassials from Križna jama is more similar to that from Gamssulzenhöhle (Austria) than that from Herkova jama (Pappa, 2010).

• The older the material is, the smaller the morphodynamic index. Thus deciduous teeth from Križna jama are almost in the same age as those from Gamssulzenhöhle and much younger than those from the Herkova jama Middle Pleistocene.

• The ratio diagram shows that there is similarity in the dimensions between the milk carnassials of *U. ingressus* from Križna jama and Loutra Almopias bear cave, as well as of *U. eremus* from Ochsenhalt, while all have smaller upper and larger lower carnassials in comparison with those of the Middle Pleistocene *U. deningeri* milk carnassials from Herkova jama.

5. Acknowledgements

The author would like to thank Professor Gernot Rabeder, Institute of Palaeontology, University of Vienna, for providing the material and making available for this study. I would especially thank him for giving me the opportunity to contribute to this book and for his helpful advice and the useful discussions on the deciduous morphotypes.

I would like also to thank Associate Professor Evangelia Tsoukala, University of Thessaloniki, for her valuable advice during the progress of this study. Finally I feel grateful to Mark Lewis, Natural History Museum of London for his comments and corrections of English, which improved this paper.

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Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:75–83, Wien 2014

The Cave Bear Incisors of Križna jama (Slovenia)

by

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Frischauf, Ch., 2014. The Cave Bear Incisors of Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:75–83, Wien.

Zusammenfassung

Dieser Artikel handelt von einer Studie an Schneidezähnen die im Laufe einer Ausgrabung im Jahr 2001, einer Kooperation der Universitäten von Laibach und Wien, geborgen worden sind. Diese Schneidezähne wurden vermessen und morphodynamisch analysiert.
Schlüsselwörter: Schneidezähne, morphodynamische Analyse, *Ursus ingressus*

Abstract

This article deals with the study of incisors that were found during the excavation from the University of Ljubljana and the University of Vienna in the year 2001. From the incisors metrical data were taken and have been morphologically analysed.
Keywords: incisors, morphodynamic analysis, *Ursus ingressus*

Element	$I^{1,2}$	I^3	I_1	I_2	I_3
Number	37	25	21	9	23
Not worn	20	10	10	2	7
Middle worn	1	6	4	1	3
Worn	14	7	6	5	12
Fragment	1	2	1	1	1

Table 1: Number and stage of occlusal wear of incisors found at the excavation 2001.

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Izvleček

Prispevek vsebuje raziskavo sekalcev (incizivov), ki so jih zbrali v času izkopavanj leta 2001. Izkopavanje so vodili sodelavci ljubljanske in dunajske Univerze. Zobe (sekalce) smo izmerili in analizirali.
Ključne besede: sekalci, morfodinamična analiza, *Ursus ingressus*

1. Material

Number and stage of occlusal wear of the incisors that were found during the excavation in 2001. The low account of i2 inf. is to be noticed, see Table 1.
About 55% of all incisors are middle worn or worn, deductively 45% of the fossil incisors belonged to young adults or pre-adults.
The abrasion and the fragmentation of the teeth reduced the number of pieces that were examined by the metrical and morphodynamic analyses. To determine the evolutionary level of the incisors the morphodynamic analysis (Rabeder, 1999) was applied. The following Table shows the number of studied incisors, see Table 2:

Element	$I^{1,2}$	I^3	I_1	I_2	I_3
Number	30	16	15	6	16

Table 2: Number of incisors included in the morphometrical analysis.

2. Stages of Occlusal Wear

The incisors were differentiated into three categories:
- **Not worn**: incisors without any traces of abrasion, germs
- **Middle worn**: incipient stages of abrasion, dental crown is partly polished
- **Worn**: big part of the dental crown is abraded or the crown is completely worn

	Length	Width	Height	Fossa lunaris index	Cingulum cusp index
Mean/index	11.0	12.1	36.3	163.64	147.50
Standard deviation	1.2	0.9	3.3		
Max.	13.1	13.8	42.0	2	3
Min.	8.0	10.0	30.0	1	0
Number	31	31	17	22	20
GS standard	**110.22**	**106.36**	**111.11**	**108.44**	**87.38**

Table 3: Means of measurements and morphological indices of I1,2 sup. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

Figure 1 shows the abrasion of all incisors. The distribution of preadult and young adults (45%) and senile animals (41%) is almost balanced. Fourteen percent of all incisors may have been adult animals. For comparison Figure 2 shows the stages of abrasion of Loutra Almopia Cave (LAC). The amount of not worn incisors is almost the same but in LAC more middle worn teeth occur than worn ones. The occlusal wear is different in the upper and in the lower jaw. Figure 3 shows the abrasion stages of the superior incisors. Within the upper incisors preadult teeth dominate. While in Figure 4 it is more balanced but the senile teeth are most frequent.

3. Deficiency of Findings

Deficiency of findings terms the fact that several skeleton elements are found in a varying number of pieces. This number of pieces is dependent on different factors, see Rabeder (2001):

• **Size**: Selection by shifting caused by running water
• **Corrosion**: small and tenuous teeth and bones are more affected by corrosion
• **Selective choosing by the excavators**: not in this case, the sediments were carefully searched through

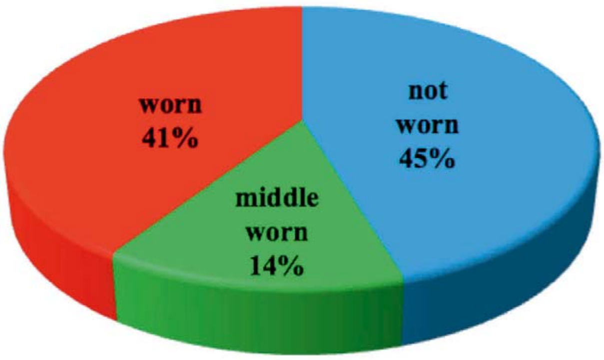

Figure 1: Stages of abrasion of all KJ incisors.

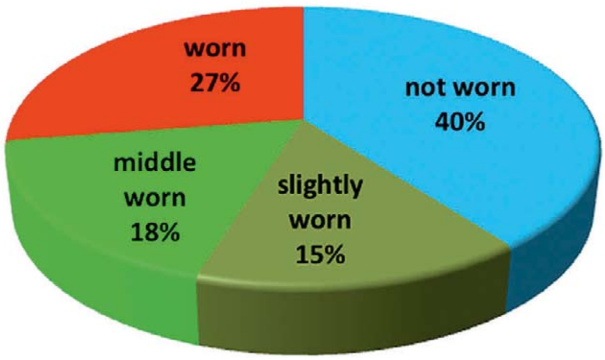

Figure 2: Stages of abrasion of all LAC incisors.

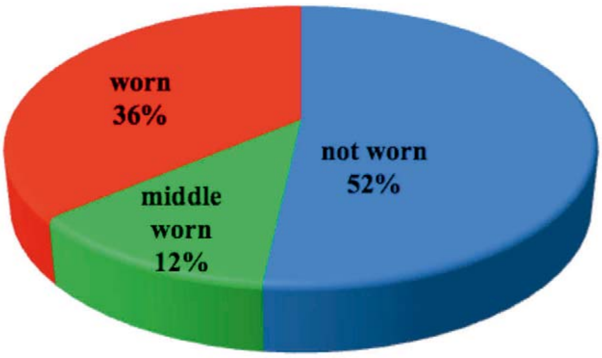

Figure 3: Stages of abrasion of upper jaw incisors from Križna jama.

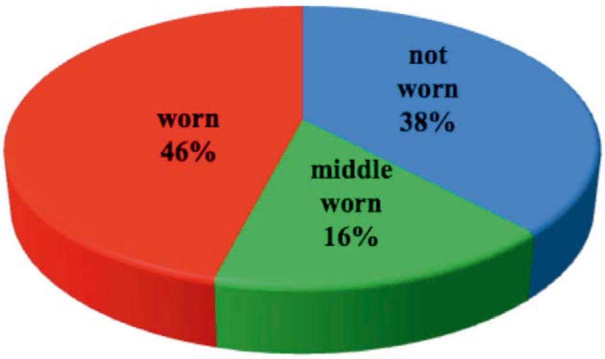

Figure 4: Stages of abrasion of lower jaw incisors from Križna jama.

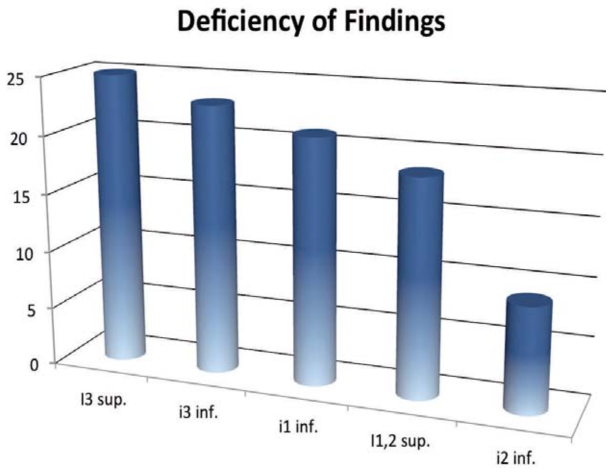

Figure 5: Deficiency of incisor findings from Križna jama.

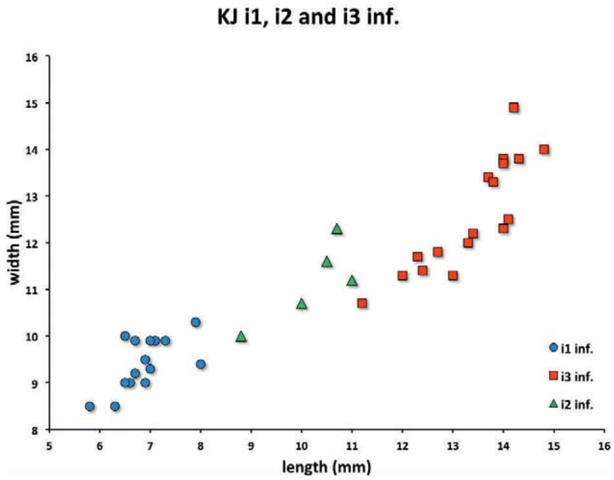

Figure 6: Scatter plot of length to width of i1, i2 and i3 inf.

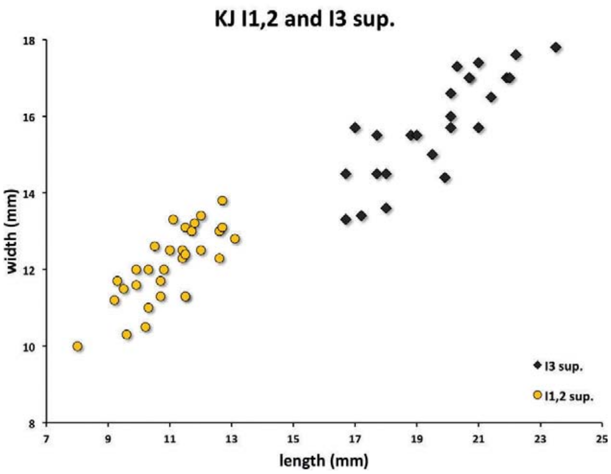

Figure 7: Scatter plot of length to width of I1,2 and I3 sup.

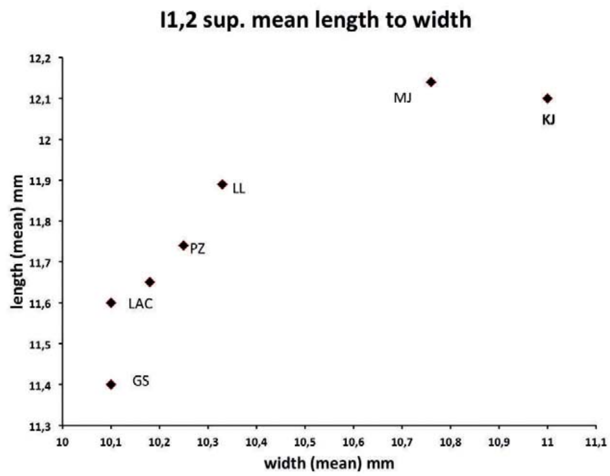

Figure 8: Scatter plot of I1,2 sup. mean length to width of *Ursus ingressus* faunas. **Abbreviations**: GS – Gamssulzen, KJ – Križna jama, LAC – Loutra Almopias cave, LL – Lieglloch, Mj – Medvedia jaskyňa, PZ – Potočka zijalka

Dimensions:
The Diagrams of Fig. 6 and 7 show the dimensions of all measured incisors of the cave bear remains of Križna jama. Compared to other European cave bear faunas the incisors of upper jaw and lower jaw are conspicuously big. The allocation of length and width values in this scatter diagram is like it is expected for a cave bear fauna. Once more it is not possible to differentiate the upper I1 and I2 by means of length and width.

4. Description

4.1. I1,2 sup.

Dimensions:
The upper I1,2 of Križna jama bear belong to the biggest found yet. Compared to other *Ursus ingressus* faunas the mean value of length is actually the biggest, see Table 3. The mean width is only surpassing by the I1,2 sup. of Medvedia jaskyňa (Slovakia) see Fig. 8.
Figures 9 and 10 show the dispersion of upper I1,2 of Križna jama, Gamssulzen cave and Medvedia cave. The KJ teeth are in the blue ellipse the one of Gamssulzen cave in the red ellipse. It demonstrates the bigger dimensions of the Križna jama. The most I1,2 sup. overlap, but in Križna jama are a few teeth bigger whereas Gamssulzen cave contains smaller teeth. Exception is the shortest of all teeth that belong to Križna jama.
Compared to the Medvedia jaskyňa I1,2 (framed with the yellow ellipse) the bigger part overlap, but in MJ we could find more small teeth but most notably wider ones than in Križna jama.

Evolutionary Level:
The upper I1,2 of Križna jama possess a relatively high evolutionary level (see Rabeder, 1999). In Fig. 11 the two indices (fossa lunaris index and cingulum cusp index) I1,2 are compared with other cave bear faunas. Križna jama fits

	Length	Width	Height	Kalyx index
Mean/index	19.65	15.76	49.57	43.33
Standard deviation	1.86	1.32	2.94	
Max.	23.5	17.8	53.8	1
Min.	16.7	13.3	45.2	0
Number	25	25	9	15
GS standard	**104.96**	**106.78**	**100.77**	**38.33**

Table 4: Means of measurements and morphological index of I3 sup. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

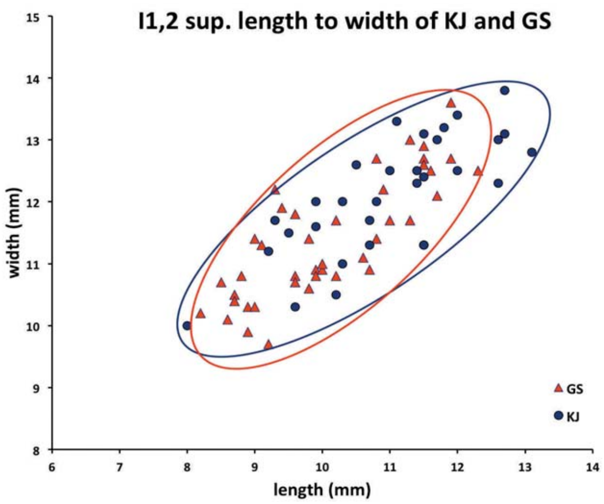

Figure 9: I1,2 sup. length to width of Križna jama and Gamssulzen cave.

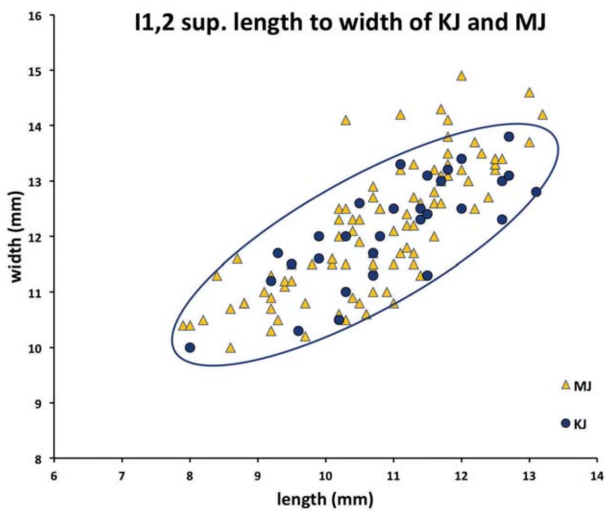

Figure 10: I1,2 length to width of KJ with GS and MJ.

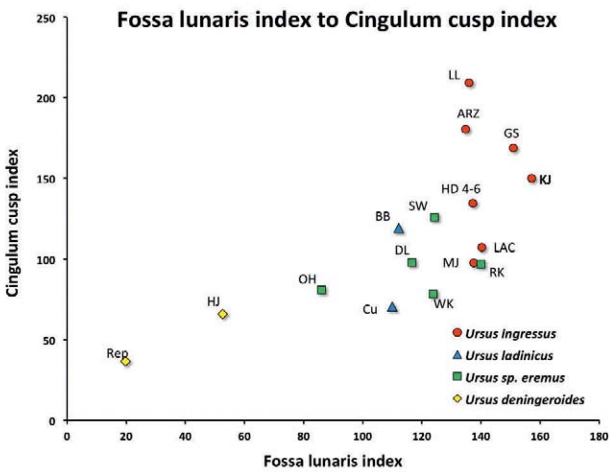

Figure 11: Fossa lunaris index to cingulum cusp index. **Abbreviations**: ARZ – Arzberg cave, BB – Brieglersberg, Cu – Conturines cave, DL – Drachenloch, GS – Gamssulzen cave, HD – Herdengel cave, HJ – Herkova jama, KJ – Križna jama, LAC – Loutra Almopias cave, LL – Liegloch, Mj – Medvedia jaskýna, OH – Ochsenhalt cave, PZ – Potočka zijalka, Rep – Repolust cave, RK – Ramesch cave, SW – Schwabenreith cave

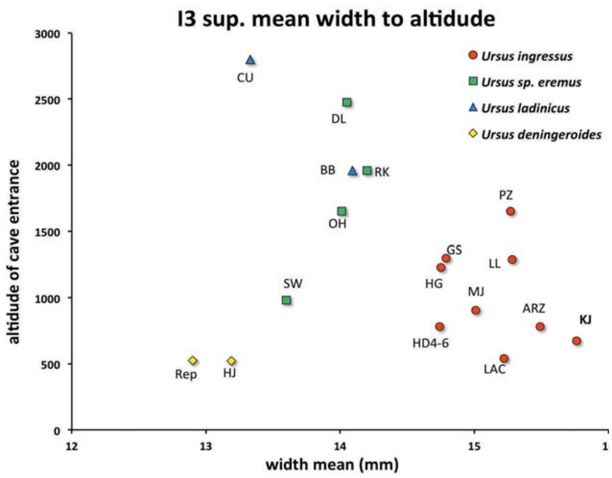

Figure 12: I3 sup. mean width to altitude of cave entrance. **Abbreviations**: ARZ – Arzberg cave, BB – Brieglersberg, Cu – Conturines cave, DL – Drachenloch, GS – Gamssulzen cave, HD – Herdengel cave, HJ – Herkova jama, HG – Hartelsgraben, KJ – Križna jama, LAC – Loutra Almopias cave, LL – Liegloch, Mj – Medvedia jaskýna, OH – Ochsenhalt cave, PZ – Potočka zijalka, Rep – Repolust cave, RK – Ramesch cave, SW – Schwabenreith cave

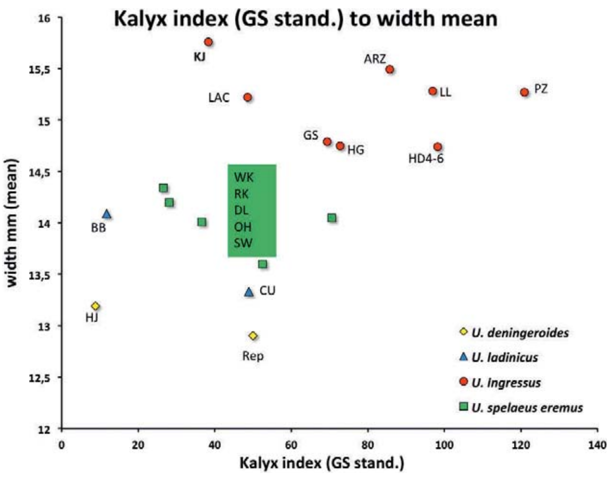

Figure 13: I3 sup. calyx index to mean width.

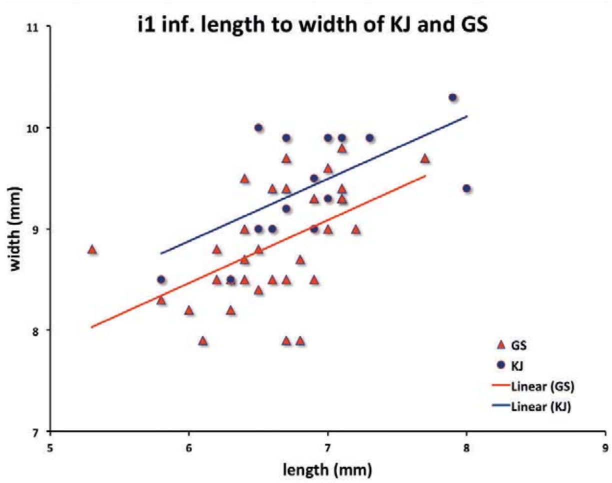

Figure 14: i1 inf. length to width of Križna jama and Gamssulzen cave.

within the *Ursus ingressus* group lying in the middle field in the development of the cingulum cusps but has the highest fossa lunaris index. Deductive there is an affinity to build a fossa lunaris and a lingual edge. 22 pieces are proper for the morphodynamic analyses. The bigger part (10 pieces) belongs to the highest fossa lunaris factor "s". This morphotype developed a fossa lunaris and a lingual edge. Eighth exemplars belong to the "r" type (with fossa lunaris but without lingual edge). The remaining four upper I1,2 are morphotype "p" (cingulum is separated by a trench). There is no "d-type", which is the evolutionary lowest. The number of cingulum cusps varied between zero and three.

4.2. I3 sup.

Dimensions:
Again the big dimensions of the Križna jama teeth can be shown articulately by comparing them with other cave bear faunas. In Fig. 12 the mean width is plot against the altitude of the cave entrance. With a mean width of 15.76 mm the upper I3 of Križna jama bear is the widest by being inhabitant of one of the geographical lowest caves. Similar results are within the other incisors.

Evolutionary Level:
The Evolutionary Level of the upper I3 is relatively low. Indeed the kalyx index does not separate the cave bear species very good. So Križna jama and Loutra Almopia Cave overlap with all *Ursus spelaeus eremus*, *Ursus ladinicus* and even *Ursus deningeroides*. Within the *Ursus ingressus* line the evolutionary level of the upper I3 spreads in a large scope (Fig. 13). The small number of adequate I3 sup. (15) that could be used for the morphdynamic analyses reduces the significance.
Six of the upper I3 belong to the "0 type". Meaning that on the distal edge there is neither a cusp nor any swelling. Another six pieces have a swelling on the distal edge therefore belonging to morphotype "0.5". Only two teeth have a cusp and belong to the type "1". I3 number KJ 11/2 has a swelling on the distal edge but also a cusp on the cingulum near the fossa lunaris. This is morphotype "1.5". There are no higher evolved teeth.

4.3. i1 inf.

Dimensions:
The i1 inf. of Križna jama are of middle size. The mean length of Potočka zijalka, Lieglloch, Arzberg cave and Medvedia jaskyňa is bigger but within the width Križna jama is only beaten by the lower i1 of Lieglloch.

Figure 14 shows the comparison between the i1 inf. of Križna jama and Gamssulzen cave. It is clearly visible that the KJ teeth are longer and wider.

	Length	Width	Height	Morphotype
Mean/factor	6.88	9.42	33.71	150
Standard deviation	0.55	0.54	2.53	
Max.	8	10.30	38.40	2
Min.	5.80	8.50	30	1
Number	15	15	15	14
GS standard	104.88	107.29	110.49	185.99

Table 5: Means of measurements and morphological index of i1 inf. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

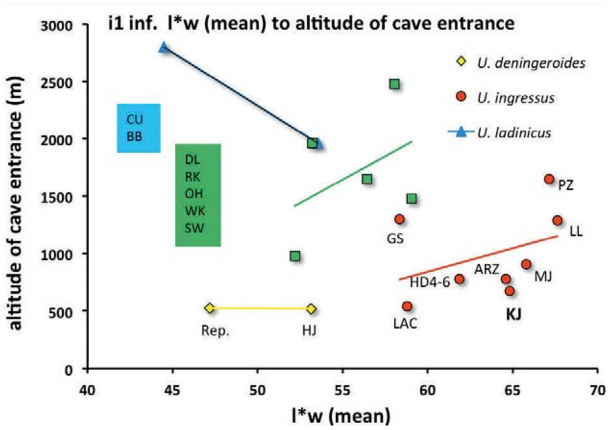

Figure 15: Mean length x width to altitude of cave entrance.

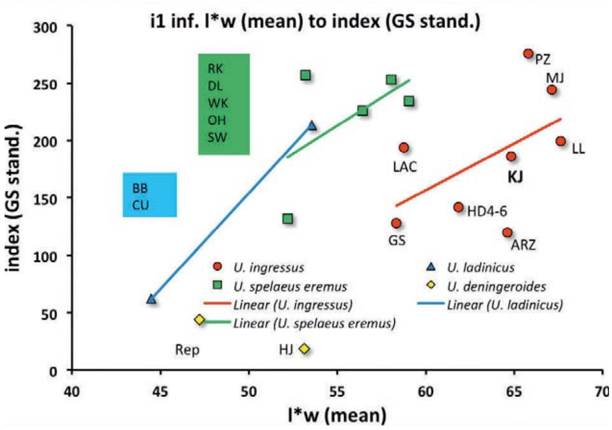

Figure 16: i1 inf. mean length x width to index (GS stand).

In Figure 15 the mean l x w (length times width) is plotted against the altitude of cave entrance. Interesting is that only *Ursus ladinicus* shows a negative correlation between the altitude of the cave entrance and the size of the lower i1. *Ursus spelaeus eremus* otherwise shows an increase in size the higher the cave entrance is situated, but within the *Ursus ingressus* line the positive correlation is the biggest.

Morphodynamic index:
Figure 16 plots the mean of length times width (l x w) against the GS standardized index of i1. Together with Loutraki Aridea cave that has the same value of morphodynamic index: 150, the Križna jama lies in the middle field. Not only other *Ursus ingressus* faunas such as Medvedia jaskyňa (with the highest evolutionary level) but also *Ursus spelaeus eremus* fauna like Ramesch-Knochenhöhle (with the 2nd highest index) and also Brieglersberg cave fauna with *Ursus ladinicus* are higher evolved. The Late Pleistocene faunas show a similar positive correlation of size and evolutionary level.
Out of the 13 lower i1 that were used for the morphodynamic analyses two teeth are associated to morphotype "A" (only protoconid and distoconid). Three lower i1 belong to the morphotype "B" (distoconid and protoconid with a partial mesial sulcus). Six teeth class with morphotype "C" (distoconid and protoconid with the mesial sulcus on the lower half of the dental crown). Morphotyp "B/C" is represented with only one tooth and is considered as intermediate stage between B and C. The highest evolutionary stage of the lower i1 development is the morphotype "D" occurring only with one exemplar (the mesial sulcus reached the tip tooth and splint of a small mesioconid). From the studies on the lower i1 it can be deduced that it is not possible to separate the cave bear species on the basis of the evolutionary level. They can be separated by their size only. It is to expect that further studies will bring more positive results.

4.4. i2 inf.

Because of the very low number of lower i2 it the mean values are not very serious.

	Length	Width	Height
Mean/factor	10.03	11.16	33.48
Standard deviation	0.80	0.79	11.53
Max.	11.0	12.3	41.8
Min.	8.8	10.0	36.0
Number	6	5	5
GS standard	103.33	102.86	91.33

Table 6: Means of measurements of i2 inf. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

	Length	Width	Height	Morphotype
Mean/factor	13.36	12.59	42.83	242.31
Standard deviation	0.94	1.16	2.13	—
Max.	14.8	14.9	47	—
Min.	11.2	10.7	40	—
Number	17	17	11	13
GS standard	101.25	101.16	100.91	94.43

Table 7: Means of measurements and morphological index of i3 inf. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

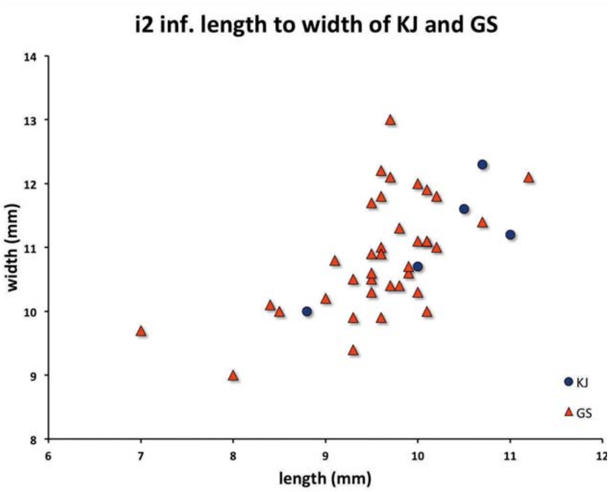

Figure 17: i2 inf. length to width of Križna jama and Gamssulzen cave.

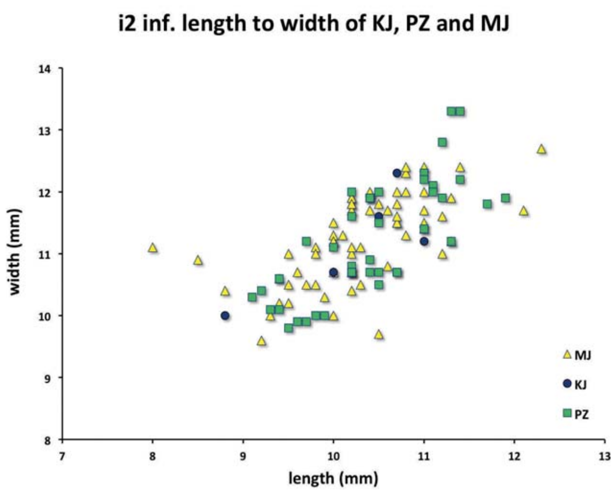

Figure 18: i2 inf. length to width of Križna jama, Medvedia jaskýna and Potočka zijalka.

Dimensions:
Figure 17 and Fig. 18: The dimensions of the lower i2 are quite big especially compared to Gamssulzen cave. Medvedia jaskýna and Potočka zijalka have bigger mean values in length and width.

Evolutionary Level:
Till now there is no morphodynamic analysis for the lower i2.

The scatter diagram of Fig. 20 compares the mean length to mean width of several cave bear faunas. The *Ursus ingressus* line separates quite clearly from the other cave bear species. While the *Ursus deningeroides* line can be distinguished from the others the *Ursus spelaeus eremus* and the *Ursus ladinicus* species are hardly to separate on basis of the dimension of the incisors.

4.5. i3 inf.

Dimensions:
Also the lower i3 of Križna jama cave bears are of big size. If you plot them in a scatter diagram (Fig. 19) against the i3 inf. of Potočka zijalka witch are the biggest of all compared cave bear faunas the main part overlap but Potočka zijalka has a few exemplars that are bigger.

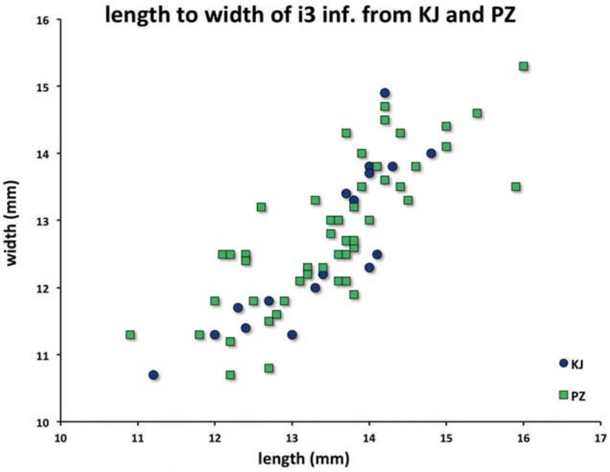

Figure 19: Length to width of Križna jama and Potočka zijalka.

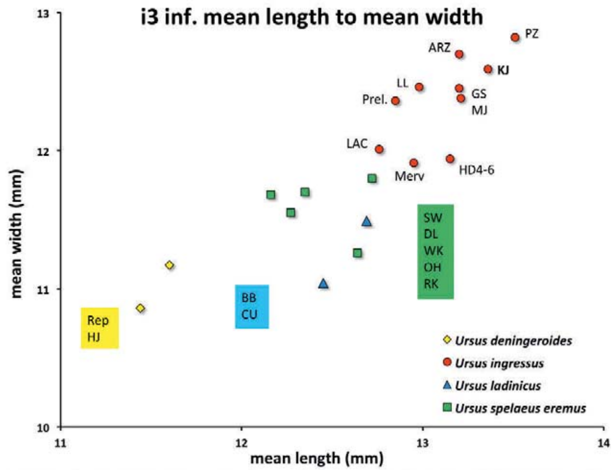

Figure 20: i3 inf. mean length to mean width of alpine and non alpine cave bear faunas.

Abbreviations: ARZ – Arzberg cave, BB – Brieglersberg, Cu – Conturines cave, DL – Drachenloch, GS – Gamssulzen cave, HD – Herdengel cave, HJ – Herkova jama, KJ – Križna jama, LAC – Loutra Almopias cave, LL – Lieglloch, Merv – Grotte Merveilleuse, Mj – Medvedia jaskýna, OH – Ochsenhalt cave, Prel – Grotte Prélétang, PZ – Potočka zijalka, Rep – Repolust cave, RK – Ramesch cave, SW – Schwabenreith cave, WK – Wildkirchli

Križna Jama: I3 sup.	**Mean Length**	**Mean Width**	**n**
Male	20.72	16.41	18
Female	17.38	14.38	8
Sex Dimorphism Index	119.24	114.17	—
	Sex Index = 30.77		

Table 8: Means of measurements and sex indices of I3 sup. of *Ursus ingressus* Rabeder et al., 2004 from Križna jama.

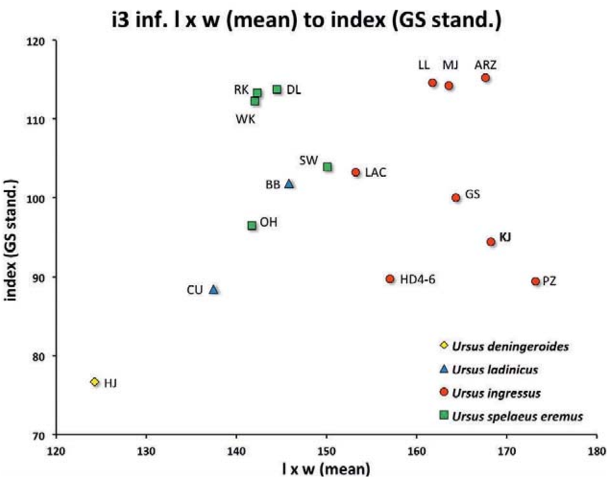

Figure 21: i3 inf. mean lenght x width to index GS standardized.

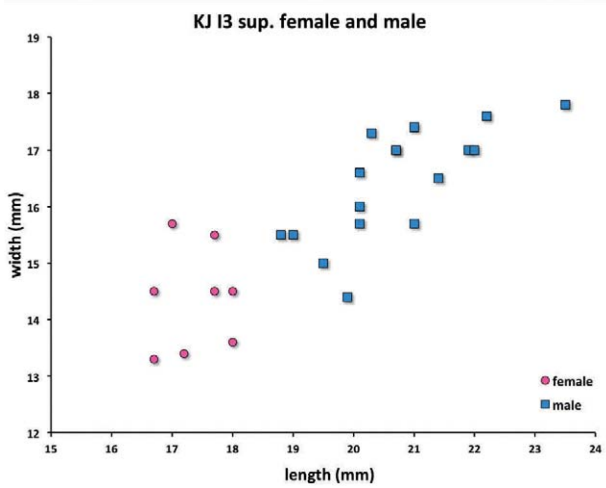

Figure 22: I3 sup. length to width of Križna jama.

Evolutionary Level:
The Evolutionary Level of the lower i3 is very low. Actually lower than most of the cave bear faunas that were compared, see Fig. 21. The lowest morphotype within the lower i3 of the Križna jama cave bear is the "C type". The sulcus mesialis and the lingual edge range from the base of the protoconid crown to the 2nd half of the protoconid crown but stop clearly below the top. Only two pieces belong to the morphotype "D". Here the sulcus mesialis and the lingual edge reach the top of the tooth crown. Five lower i3 class with the intermediate form "C/D" and one i3 inf. is of the intermediate form "C/E1". E1 morphotype is defined by a small cusp on the mesial side of the Protoconid.

5. Sex Index and Sex Dimorphism Index

Figure 22 plots the length against the width of the upper I3. A fictional line separates the smaller female teeth (pink dots) on the left from the bigger male teeth (blue dots) on the right. This line would support the perceptions of the sex index of the canines. With a sex index of 30.77 the Križna jama cave has a noticeable male dominance. Also the other teeth elements tend to have more big sized teeth. The male dominance is a reason of the big dimensions of the teeth but at all the teeth elements contain bigger teeth than in other caves. There is an obvious sex dimorphism within the dimensions of the upper I3. The Sex Dimorphism Index (119.24) of mean length is quite high. Compared to the Gamssulzen cave's I3 sup. with a sex index of 62 the SDI in length is only 114.12.

6. Conclusions

Unfortunately the amount of teeth to study was quite low. Especially the lower i2 included only five exemplars. The element with the most pieces is the upper I3. To hypothesize the size can be a factor in the deficiency of finding might be wrong considering the rare findings of upper I1,2 and the relatively frequent lower i1.
Conspicuous are the big dimensions of the teeth what is not only a result of the male dominance. All teeth elements belong to the biggest, only sometimes the fauna of Medvedia cave or Potočka zijalka is of bigger size. Within the evolutionary level the incisors of Križna jama are of low to middle development. The incisors of the Križna jama cave bear fit the values of dimension and Evolutionary Level of *Ursus ingressus*.

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Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:85–96, Wien 2014

Skeletal Element Distribution and Metrical Analyses of Cave Bear Remains from Križna jama (Slovenia)

by

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Pacher, M., 2014. Skeletal Element Distribution and Metrical Analyses of Cave Bear Remains from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:85–96, Wien.

Zusammenfassung

Križna jama im slowenischen Karst ist eine reiche Höhlenbärenfundstelle. Jedoch war ein Teil der Funde, die Hochstetter (1881) aufzählt, nicht auffindbar. Das vorhandene Material besteht aus 4745 Knochen- und 520 Zahnresten. Kleine Skelettelemente sind im Material der der älteren Grabungen unterrepräsentiert. Das von Hand durchsuchte Material der neuen Grabungen 1999 und 2001 weist deutlich mehr kleinere Elemente auf.
Die metrische Auswertung von Eckzähnen, Schädeln, Unterkiefern und Langknochen belegt ein Überwiegen von männlichen Tieren im Fundmaterial der Križna jama. Die Masse einiger Stücke übertreffen jene der Vergleichsmaterialien aus dem genetisch eng verwandten Material aus der Gamssulzenhöhle, Österreich und der Potočka zijalka, Slowenien. Generell sind die Größenverteilungen für beide Geschlechter in allen drei Fundstellen ähnlich und kleinere Unterschiede auf die teilweise geringe Anzahl messbarer Stücke zurückzuführen.
Schlüsselwörter: Elementverteilung, Metrik, Höhlenbär, Križna jama, Slowenien

Abstract

Križna jama in the Slovenian karst area is a rich cave bear site but part of the material listed by Hochstetter (1881) is missing. The available assemblage consists of 4745 bones and 520 teeth remains. Small elements are clearly underrepresented in the material of the older excavation campaigns. The hand screened material from the new 1999 and 2001 campaigns shows a better representation of small elements.
Metrical analyses on canines, crania, mandibles, and long bones indicate a male dominated cave bear assemblage at Križna jama. In long bones, some specimens from Križna jama are larger than the comparative material from the genetically closely related sites Gamssulzen-cave, Austria and Potočka zijalka, Slovenia. In general, size ranges of both sexes are similar at all three sites and observed differences may be explained by partly low sample size.
Keywords: element distribution, metrical analyses, cave bear, Križna jama, Slovenia

Izvleček

Križna jama s slovenskega Krasa je bogato najdišče ostankov jamskega medveda. Vendar del najdb, ki jih omenja Hochstetter (1881) nismo našli. Pri izkopavanju zbran material predstavlja 4745 kosti in 520 zob. Manjše kosti skeleta so slabše zastopane. V letih 1999 in 2001 smo pri izkopavanjih zbrali neprimerno več manjših delov okostja.
Meritve podočnikov, lobanj, spodnjih čeljustnic in dolgih kosti kažejo na prevlado moških osebkov (samcev) med najdbami iz Križne jame. Velikost nekaterih delov okostja presega enake najdbe iz genetsko sorodnega materiala iz jame Gamssulzenhöhle v Avstriji in iz Potočke Zijalke v Sloveniji. V glavnem je porazdelitev velikosti obeh spolov podobna v vseh treh najdiščih. Majhne razlike so deloma posledica premajhnega števila merljivih kosov.
Ključne besede: porazdelitev najdb, meritve, Križna jama, Slovenija

1. Introduction

Die Križna jama or Kreuzberghöhle is situated near Bloška Polica in the Slovenian karst area. Its main attractions are over 40 underground lakes flowing over sinter cascades. Besides important bat colonies it is famous for over 40 troglobiontic species.

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Element	Hochstetter (Listed)	NHMW (stored)	IPUW	NML	New Excav.
Crania	35	11	—	42	149
Mandibulae	90	36	1	56	56
Atlas	59	17	1	4	12
Epistrophei	28	6	1	5	8
Vertebrae cerv.	194	27	—	13	—
Vertebrae thor.	455	31	1	51	28
Vertebrae lumb.	221	14	2	11	31
Vertebrae caud.	49	1	—	—	7
Costae	732	—	3	200	148
Sterna	65	8	—	—	12
Scapulae	48	2	—	13	26
Humeri	89	61	2	19	27
Radii	115	98	1	13	40
Ulnae	125	94	4	54	37
Carpals	169	101		11	103
Metacarpals	453	319	4	55	106
Pelvis	27	18	2	17	26
Sacrum	49	6	2	—	5
Femora	125	88	—	37	40
Tibiae	157	115	—	16	30
Fibulae	75	50	—	19	39
Astragali	—	15	2	10	21
Calcanei	—	22	3	13	21
Tarsals	194	21	3	2	—
Metatarsals	483	369	7	49	107
Phalanges	349	2	—	—	—
Phalanx 1	—	186	2	12	192
Phalanx 2	—	3	—	1	115
Phalanx 3	110	24	—	—	117
Patellae	50	6	—	2	18
Sesamoids	—		—	—	112
Hyalia	61	2	—	—	15
Bacula	21	—	—	2	3
Vertebrae	—	7	—	13	6
Metapodials	—	21	—	1	—
Total	**4628**	**1928**	**39**	**741**	**2037**

Table 1: Skeletal element distribution of the Križna jama material according to collections (NHMW … Museum of Natural History Vienna, IPUW … Institute of Paleontology Vienna, NML … National Museum Ljubljana).

In addition, finds of cave bear remains were long known. They were also collected by local farmers as medical treatments and various other visitors. First scientific excavations were undertaken by Hochstetter from the Natural History Museum in Vienna from July, 19th – 22nd 1878. From August, 1st – 9th 1879 J. Szombathy and E. Kittl accompanied him. His finds came from two terraces, the Monumentenhügel and mainly the Bärenwirtshaus. The material housed at the Narodni muzej BTC Ljubljana comes from the investigations from Brodar & Gospodarič (1973).

Finally, the Institute of Paleontology in Vienna in cooperation with the Oddelek za geologijo excavated in the bear's cave in 1999 and in the Kittl's bear cave in 2001.

2. Chronology

Samples of cave bear bones from the new excavations were taken for AMS radiocarbon dating and aDNA analyses. Four samples gave consistent ages from 44,800 up to 46,700 yrs BP (Rabeder & Withalm, 2001). One sample indicates a younger occupation phase at Križna jama around 32,550 yrs BP. For details of the chronology see Rabeder (this volume). Uran-Thorium dating of flowstone remains at the site Medvedji rov resulted in six ages ranging from 126 ka until 173 ka (Bosak et al., 2010), which indicate complex site formation processes as can be expected in a cave frequently affected by water torrents until today.

3. Material

The studied material comes from the excavation by Hochstetter and Kittl housed in the Natural History Museum in Vienna. Altogether 4600 bones of various age classes were collected and probably the same amount could not be collected due to bad preservation. Based on tibia 80 individuals are represented according to Hochstetter (1881).

Hochstetter mentioned about 2000 bones collected in 1878. Among them were also some complete skeletons, from which he mounted two complete skeletons that were on display in the Natural History Museum of Vienna. Unfortunately only parts of it could be found at the collection. Altogether 1928 bones out of 4628 listed by Hochstetter (1881) were found at the museum's collection (Table 1). In addition 144 isolated teeth are preserved (Table 2). The new excavations in 1999 and 2001 yielded 2037 determined cave bear bones and 371 teeth remains. This material will be stored at the Oddelek za Geologijo in Ljubljana. The third larger collection is stored at the Narodni muzej BTC Ljubljana and comprises 741 determined cave bear remains. Three teeth come from this collection. A small collection at the Institute of Palaeontology in Vienna contains 41 bones and teeth. The finds listed in Hochstetter (1881) came from two terraces, the "Monumentenhügel" and mainly the "Bärenwirtshaus" in an area called "Hochstetter's Schatzkammer" (Medvedji rov, bear gallery). There a 0.7 to 0.8 m thick layer of loam was excavated in around 25 m^2. Beneath the loam followed a flowstone layer. The loam was searched through by hand.

Kittl excavated in a small area called Kittl's Bärenhöhle (Kittlovo brezno). Beneath a 0.2 to 0.3 m flowstone layer was 0.5 to 1 m humid sticky loam package with bones, among them eight skulls and associated skeletons. Hochstetter reported of one individual above the other and even neonate skeletons completely preserved. Unfortunately their preservation was so poor that most of the remains could not be collected. Both sites lay at the same level, about 10 to 12 m below the cave entrance. The material from Brodar and Gospodarič came also from the area of Medvedji rov. The large cave bear assemblage of Križna jama shows a biased preservation of remains, which is due to recovery techniques and preservation. Already Hochstetter (1881) mentioned the poor state of preservation of certain specimens that could not be collected. A comparison of the inventory list given by Hochstetter and the available remains at the Natural History Museum in Vienna indicate a loss of remains later on. For measurments see Appendices 1–3.

Element	IPUW	NHMW	Excav.	NML
Deciduous teeth			68	
I1 inf.			21	
I2 inf.			9	
I3 inf.			22	
C inf.		2	28	
P4 inf.			26	
M1 inf.		34	31	
M2 inf.		19	28	
M3 inf.	1	15	29	
I1+2 sup.			30	
I3 sup.			25	
C sup.	1	6	7	1
P4 sup.		12	25	1
M1 sup.		19	22	
M2 sup.		22	28	
Canines			33	1
Molars				
Incisors		12	7	
Total	2	144	371	3

Table 2: Quantitative distribution of cave bears teeth from Križna jama (no isolated teeth mentioned by Hochstetter, 1881), abbreviations as in Table 1.

4. Metrical Analyses

A comprehensive metrical analysis was undertaken on crania, mandibles, and long bones. To the extent possible, specimens were determined as males or females. In order to compare size ranges, the material was then compared to measurements obtained on bones from Gamssulzen-cave and Potočka zijalka. Gamssulzen-cave lies at 1,300 m a.s.l. in the Totes Gebirge, Upper Austria and is regarded as type locality of the so-called *U. ingressus* (Rabeder et al., 2004). Several direct dates place the remains into the time span of approx. 38 ka to 25 ka BP (Frank & Rabeder, 1997). Potočka zijalka is a high Alpine cave site at 1,700 m a.s.l. in northern Slovenia. The rich cave bear assemblage covers a similar time span from 36 ka to 26 ka BP (Rabeder & Pohar, 2004).

Sexing of skulls and mandibles is best undertaken by measuring the crown width of the canines, that is the

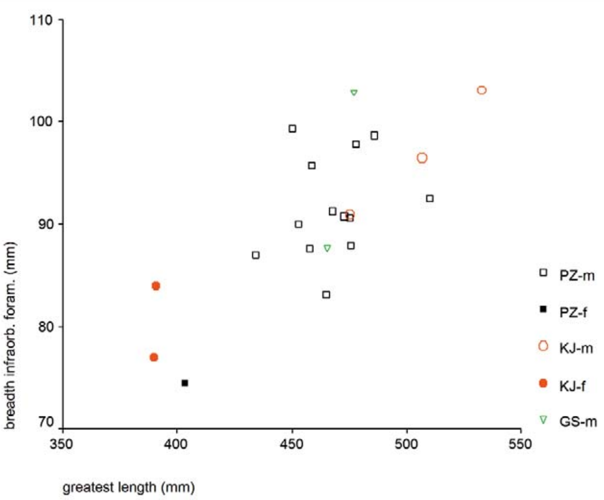

Figure 1: Comparison of cranial total length and snout width (between infraorbital foramina) of adult crania between sexes and sites (PZ … Potočka zijalka, KJ … Križna jama, GS … Gamssulzen-cave), m … male, fem … female

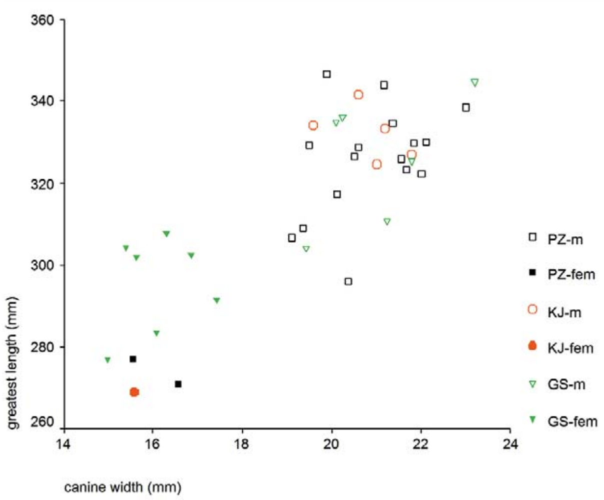

Figure 2: Comparison of canine width and total length of adult mandibles between sexes and sites (PZ … Potočka zijalka, KJ … Križna jama, GS … Gamssulzen-cave), m … male, fem … female

transversal diameter at the base of the enamel. Although upper canines are slightly less reliable in sexing than lower ones (Kurtén, 1955:12), it was possible to attribute all specimens from Križna jama to sexes. The bimodal distribution observed in canines is commonly concluded to represent females and males. However, the classification of specimens within an intermediate size range will always remain tentative. In case of cave bear canines the possible error is very low.

Potočka zijalka and Križna jama are male dominated while in Gamssulzen-cave females outweigh (see also Pacher & Quiles, 2013). The classification of the three sites into male respectively female dominated assemblages is in accordance with the approach by Rabeder (this volume).

The assemblage from Križna jama contains six completely preserved skulls, three come from the collection Hochstetter and three from the new excavation. Hochstetter (1881) mentioned eight complete skulls, but only three were found at the museum's collection. The available specimens belong to four males and two females and are compared to crania from Potočka zijalka and Gamssulzen (see Pacher, 2004a). One specimen from Križna jama is missing in Fig. 1.

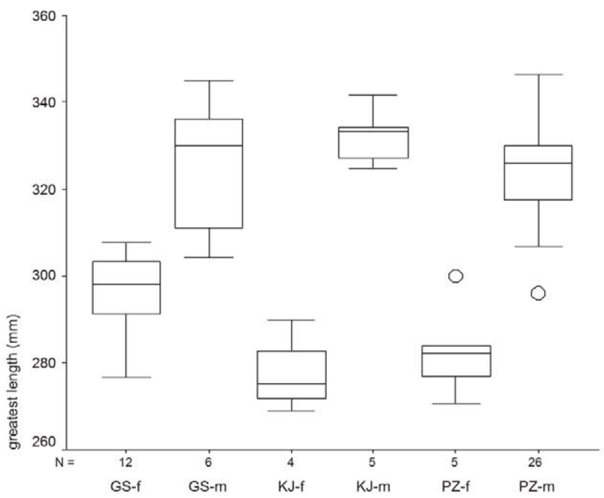

Figure 3: Comparison of greatest length of mandibles between sexes and sites (PZ … Potočka zijalka, KJ … Križna jama, GS … Gamssulzen-cave), m … male, fem … female

In mandibles, sexual dimorphism in size is also expressed especially in the total length, the height of the mandible and the diameter of the condylus mandibularis (Kurtén

Site	Sex	n	Min.	Max.	Mean	SD	D
KJ	F	4	269.0	290.0	277.37	8.93	1.20
	M	5	324.76	341.62	332.10	6.62	
GS	F	12	276.8	307.9	296.23	9.18	1.15
	M	5	304.2	345.0	326.08	15.74	
PZ	F	5	270.8	300.0	282.8	10.9	1.15
	M	26	295.8	346.6	325.42	11.84	

Table 3: Statistics and sex-ratios calculated on greatest length of mandibles from Križna jama (KJ), Gamssulzen-cave (GS) and Potočka zijalka (PZ), **F** … female, **M** … male, **D** … dimorphism calculated as the ratio of the male mean to the female mean (Van Valkenburgh & Sacco, 2002).

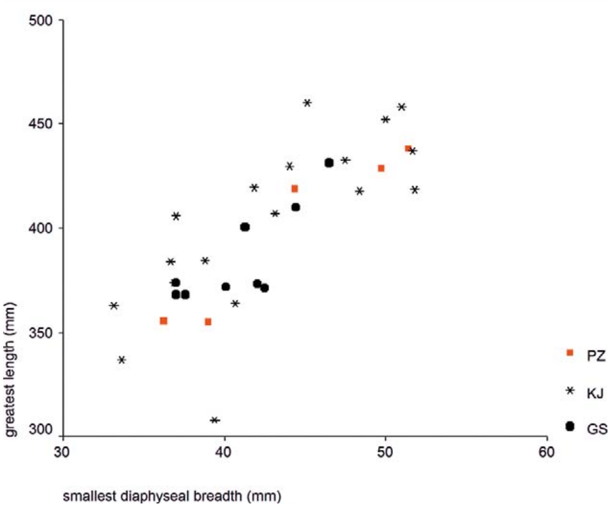

Figure 4: Greatest length and smallest diaphyseal breadth of humeri from Križna jama (KJ), Potočka zijalka (PZ) and Gamssulzen-cave (GS)

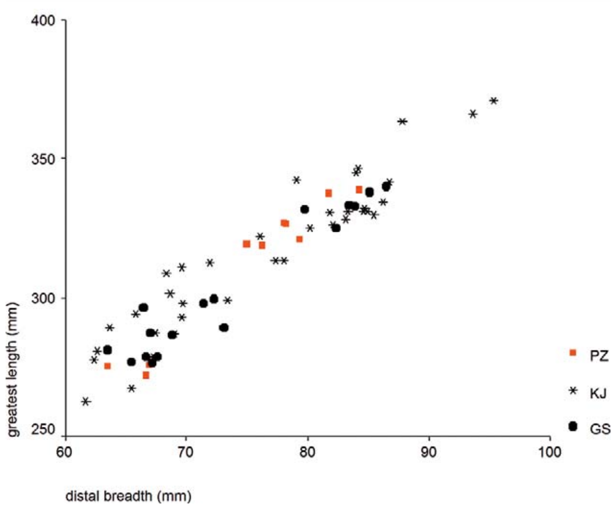

Figure 5: Greatest length and distal breadth of radii from Križna jama (KJ), Potočka zijalka (PZ) and Gamssulzen-cave (GS)

1958; Pacher, 2004b). At Križna jama nine mandibles are completely preserved. They fall into four females and five males. The total length of the specimen is in accordance with values obtained from Gamssulzen-cave and Potočka zijalka. While the few females from Potočka zijalka and Krizna jama lie at the lower range of values (Fig. 2, Fig. 3, Table 3), the males from Križna are within the observed distribution ranges.

Long bones of the Križna jama bears were sexed by comparison of length and breadth measurements (greatest length, proximal breadth, smallest breadth of the diaphyses, distal breadth). Using various univariate and bivariate plots it was possible to determine most of the complete specimens according to gender (Table 4). The classification of some specimens though stays ambiguous. Charts that gave the clearest results are shown.

At Križna jama 21 humeri were completely preserved. They are classified as ten females and eleven males. The segregation into two groups is best shown in the greatest length and the smallest breadth of the diaphyses (Fig. 4) when compared to the assemblage from Potočka zijalka and Gamssulzen-cave. Numerous measurable radii from Križna jama fall into 17 females and 20 males. Compared to values from Potočka zijalka and Gamssulzen-cave, three males are considerably larger than the samples from the latter two sites (Fig. 5). 42 ulnae from Križna jama fall into two clear size groups resulting in 18 females and 24 males. They cover the range of values shown by the samples from Gamssulzen-cave and Potočka zijalka with some larger male individuals (Fig. 6). The rather small number of measurable femora from Križna jama consists of seven females and four males. The more numerous tibiae from Križna jama consist of 29 females and 15 measurable specimens from males. The males from both, femora and tibiae lie again on the upper range of the size distribution shown by the assemblage from Gamssulzen-cave and Potočka zijalka (Fig. 7, Fig. 8).

The total length of fibulae shows a bimodal distribution (Fig. 9). The segregation of males and females was based on the results obtained by Reisinger & Hohenegger (1998) but stays ambiguous due to lack of additional measurements.

KJ	Female				Male					D
	min	max	mean	SD	min	max	mean	SD	F:M	
Humerus	308.0	348.0	350.2	27.21	406.0	460.0	430.8	19.26	10:11	1.23
Radius	263.0	312.5	290.2	14.27	313.0	370.7	336.2	15.92	17:20	1.15
Ulna	308.0	367.0	338.8	16.61	372.0	425.0	391.1	11.9	18:24	1.15
Femora	364.5	416.0	387.8	19.36	441.0	494.5	468.9	22.6	7:4	1.21
Tibia	237.4	282.3	266.4	11.66	283.1	340.4	308.2	13.41	29:15	1.16
Fibula	225.0	260.0	240.0	11.66	265.0	300.0	277.3	15.16	10:4	1.16

Table 4: Comparison of the greatest length (mm) in long bones from Križna jama (KJ), Gamssulzen (GS), and Potočka zijalka (PZ) for males and females. D … dimorphism calculated as the ratio of the male mean to the female mean (Van Valkenburgh & Sacco, 2002).

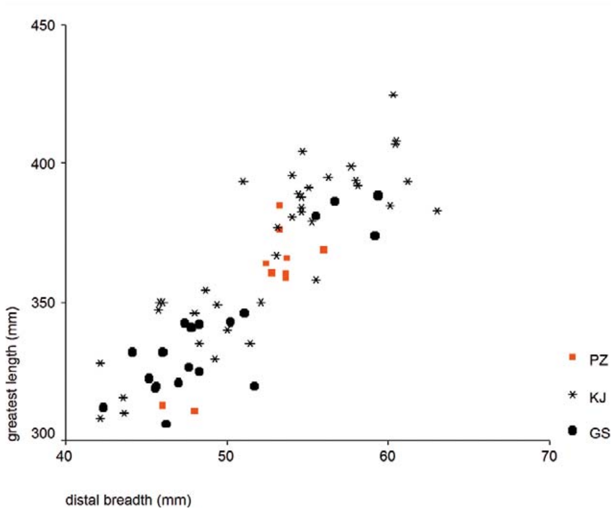

Figure 6: Greatest length and distal breadth of ulnae from Križna jama (KJ), Potočka zijalka (PZ) and Gamssulzen-cave (GS).

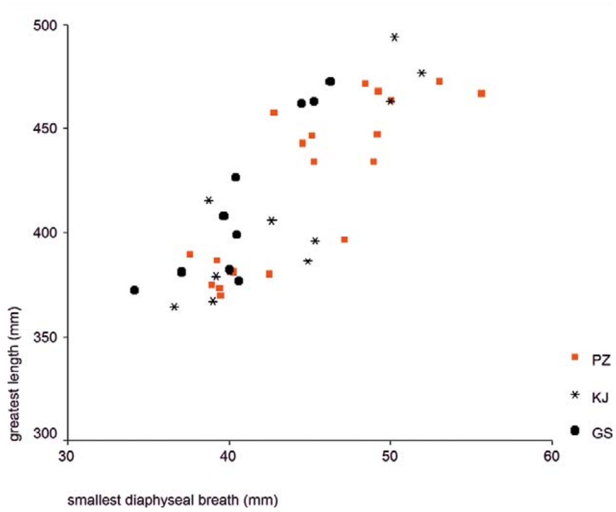

Figure 7: Greatest length and smallest diaphyseal breadth of femora from Križna jama (KJ), Potočka zijalka (PZ) and Gamssulzen-cave (GS).

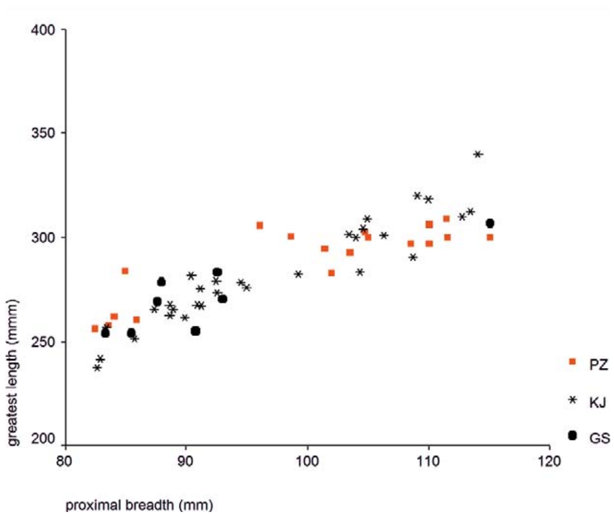

Figure 8: Greatest length and proximal breadth of tibiae from Križna jama (KJ), Potočka zijalka (PZ) and Gamssulzen-cave (GS).

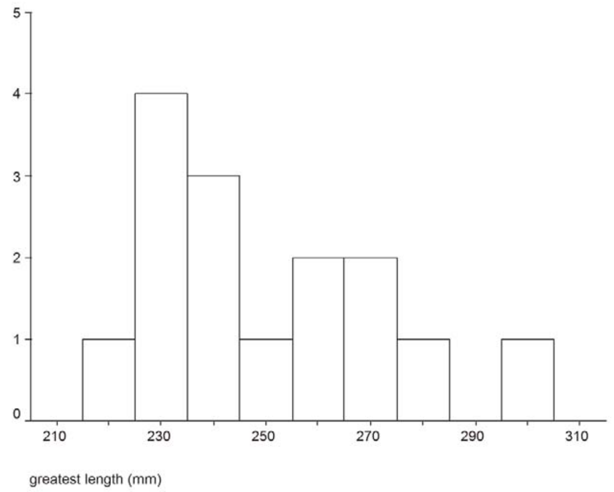

Figure 9: Greatest length (mm) of fibulae from Križna jama.

5. Summary

The available cave bear material from Križna jama is a clearly male dominated assemblage. The size ranges for crania, mandibles and long bones are in good accordance with ranges observed at Gamssulzen-cave, Austria and Potočka zijalka, Slovenia.
Single larger specimens are observed at Križna jama, especially in long bones. The values obtained from the Križna jama bears lie within ranges observed at Late Pleistocene cave bear assemblages (see Pacher & Quiles, 2013).

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APPENDIX 1

Measurements (in mm) of cave bear crania from Križna jama (tl … total length, bl … basal length, gmb … greatest mastoid breadth, gbo … greatest breadth of the occipital condyles, gbf … greatest breadth of the foramen magnum, gzb … greatest zygomatic breadth, lbt … least breadth of the temporalia, gfb … greatest frontal breadth, lbo … least breadth between the orbits, lpb … least palatal breadth, ld … length of diastema, cw … crown width of upper canine, bif … breadth between the infraorbital foraminae, gpb … greatest palatal breadth)

No.	tl	bl	gmb	gbo	gbf	gzb	lbt	gfb	lbo	lpb	ld	cw	bif	gpb
A5335	390	347	203.5	73	31	226	71.3	110		64.1	43.7		77	
A5330	391	356	215	70	32		79.5	117.4	82.2	67.4	45.7	17.1	83.9	92.8
no.	475	425		83	34	292	84.5	133.8	103.9	67.7	49.3	21.5	91	
KJ 216	506.6	445.9	265.2	92.25	42.1	300.5	90.5	148.9	105.94	76.0	59.6	25	96.5	116.5
KJ 215	532.6	466.2	266.3	93.5	40.1					81	59.5	22.4	103.2	
KJ 214														

APPENDIX 2

Measurements (in mm) of cave bear mandibles from Križna jama (tl … total length, ld … length of diastema, hmp4 …height of mandible below p4, hmm1 … height of mandible below m1, hmm3 … height of mandible below m3, wmp4 … width of corpus mandibulae anterior of p4, wmm3 … width of corpus mandibulae anterior of m3, lct … length of cheek teeth row, bcm … breadth of condylus mandibularis, dcm … diameter of condylus mandibularis, cw … crown width of lower canine, cl … crown length of lower canine, th … total height of mandible, ha … height from processus angularis)

No.	tl	ld	hmp4	hmm1	hmm3	wmp4	wmm3	lct	bcm	dcm	cw	cl	th	ha
NHMW	269	52.1	54.5	53.1	63	21.7	27.3	91.7	62.9	23	15.6	20	141	118.4
KJ 189	275	46.4	54.9	56.6	62.7	20.6	23.8	99.3						
NHMW-9	290	52.5			62.2			106						
KJ 228	324.76	62.6	73.2	76.1	82	23.4	32	103			21	28.3	175.8	147.86
NHMW	327	59						102	76.8	30	21.8		188	155
KJ 4	333.14	56.3	74.8	72	78.6	28.3	31.5	104.8			21.2	25	166.8	149.04
NHMW-1	334	55.9	69.7	68.2	72.3	24.3	33.7	101	70	29.2	19.6	26.2	160	181
KJ 231	341.62	63.5	80.6	80	86.4	25.5	29.2	105.8	81.3	27.6	20.6	28	183.4	143.27

APPENDIX 3

Measurements (in mm) of cave bear long bones from Križna jama (gl … greatest length, pl … physiological length, pb … proximal breadth, pd … proximal depth, sd … smallest diaphyseal breadth, db … distal breadth, bt … breadth of trochlea, bda … breadth distal articulation, hpat … height proc. anconaeus to tuberculum, dpa … depth across proc. anconaeus, bpc … breadth processus coronarii, dc … depth of caput femoris, 1 … sin., 2 … dext.)

No.	Side	gl	pl	pb	pd	sd	db	bt	bda	hpat	dpa	bpc	dc
HUMERUS													
KJ-197	2	320											
NHMW-sub	2	328		65			109.3						
NHMW-15	1	337	332	67.9	83.4	33.7	99.4	71.08					
NHMW-22	2	340	330				98.95	74.12					
NHMW-7	1	363	355	67.7	68.2	33.2	100.5	66.97					
NHMW-2	1	364	361	79		40.7	100.7	78.9					
NHMW-21	2	374	366	72.1	93.7	36.9	101.7	73.3					
NHMW-19	2	384	375	80.7		38.8		83.5					
NHMW-1	2	406	398	80	104	37	117	80.7					
NHMW-18	1	407	397	84.4	104	43.12	125.7	82					
NHMW-rek	1	418	409	94.7	110	48.4	127.5	87.2					
NHMW-rek	1	418	409	94.7	110	48.4	127.5	87.2					
NHMW-rek	2	418.5	409	90.09	111.3	51.8	126.5	88					
NHMW-rek	2	419	409	90.09	111.2	51.8	126.5	88					
NHMW-12	2	419.5	410	88.6	108.5	41.8	134	87.4					
NHMW-14	1	430	420.5	92.7	107.9	44	127.6	85.9					
IPUW	2	432.8	425.3	89.42	107.85	47.5	122.08	90.9					
IPUW	1	437.22	426.4	112.9	112.85	51.66	137.36	96.95					
NHMW-17	2	452	444	99	124.4	50	134	86.5					
NHMW-20	2	458	446.5	98	116.3	51		102.6					
NHMW-13	2	460	450	97.5		45.2	135.3	93					
RADIUS													
NHMW-14	1	263	248.7	56.5		24.5	61.8		42.3				
NHMW-9	1	267.6	257.8			28.7	65.5		46.5				
NHMW-31	2	277.5	262.4			28	62.4		47.1				
NHMW-8	2	279	253.9	43.3		29.9	67.3		50.3				
NHMW-31	2	280.5	265	54.1		30.7	62.7		47.6				
NHMW-26	2	283.2	266.5			30.0			46				
NHMW-11	2	287	270	56.6		31.9	69		54.4				
NHMW-12	1	287.5	268.5	44.9		33.6	67.5		48				
NHMW-38	2	289.2	266.6	43.1		30.7	63.7		46				
NHMW-35	2	292.8	276.3	45.8		30.9	69.6		49.4				
NHMW-15	2	294.2	278.2	38.6		28.5	65.9		50.7				
NHMW-7	1	297.9	275.8	44.4		19.7	69.7		48.5				
NHMW-16	2	299	282.9	42.9		26.6	73.4		51.9				
KJ-171	1	301.5	278.29	48.19	35.4	32.13	68.68		50.9				
NHMW-23	2	309	283.7			32.5	68.4		49.3				
NHMW-34	2	310.9	292.9	47.8		31.5	69.6		51.8				
NHMW-4	1	312.5	287.6	44.8		29.9	71.9		49.4				

No.	Side	gl	pl	pb	pd	sd	db	bt	bda	hpat	dpa	bpc	dc
KJ-47	1	312.99	287.14	47.8	39.4	32.35	77.27		54.7				
NHMW-6	1	313	286	48.6		33.8	78		53.6				
NHMW-2	1	314.5	309	59.3		27.3	86.7		64.6				
NHMW-22	2	321.9	301			36.7	76		58.5				
NHMW-1	2	325	296.7	51.4		40.2	80.2		54.9				
KJ-187	1	326.34	296.73	52.91	42.44	35.86	82.05		55.09				
NHMW-20	2	328.5	301.8	59.4		37.5	83.2		61.7				
NHMW-17	1	330.2	302	42.4		36.5	85.5		59.7				
NHMW-37	2	330.5	310.2	51.4			81.8		61				
NHMW-10	1	330.9	303	43		41.2	84.6		60				
NHMW-3	1	331	294.8	55.2		3.9	83.3		60.3				
NHMW-rek	1	331	308	53.1	38.6		84.9						
NHMW-18	2	332.1	313.7	53.9		38.2	84.7		60				
NHMW-24	1	334.7	308.1	44.9		40.6	86.2		63.4				
NHMW-5	1	342.2	318.3	52.9		35.7	79.1		58				
NHMW-36	2	345	322.4			44	84		63				
NHMW-32	2	346.5	324.8	56		34.4	84.1		61.7				
NHMW-33	1	363.5	335.7	55		38.5	87.8		60.3				
NHMW-13	1	366.1	338.5	48.3		36.8	93.6		62.9				
NHMW-19	2	370.3	349.3	53.7		38.4	95.3		65.4				
ULNA													
NHMW-35	1	308		72.7			42.2			68.8	70		
NHMW-37	2	310		72.97			43.7			75.6	67.4		
NHMW-46	2	315.5		63.5			43.6			71.7	59	55.5	
NHMW	1	327											
NHMW-34	1	328		69			42.2						
NHMW-33	1	329.5		57.4			49.3			80.24	69.3		
NHMW-19	1	335		71			48.3						
NHMW-32	1	335		79.7			51.4			83.95	74.7		
NHMW-41	2	340		72.1			50			81.94	70	59.4	
NHMW-43	1	346		76			48			85.4	70.8	61.7	
NHMW-30	2	347		67.9			45.8			63	63.6	51	
NHMW-29	1	349		74.05			49.4			89.4	73.2	57	
NMLj-113-1	1	350		72.5			45.9						
NHMW-6	1	350.05		81			46.1			80.3	72.5		
NHMW-16	1	350.05		71.06			52.1			83.8	68.07		
NHMW-27	1	354		80.7			48.7			80.4	78.5		
NHMW-12	2	358		80.67			55.6			74.76	89.4		
NHMW-8	1	367		81.9			53			88.96	80.4	66.2	
NHMW-23	1	372		96.6						104.96	89.3		
NHMW-18	1	377		88.6			53.1			57.6		63.67	
NHMW	1	377											
KJ-176	1	379		90.6			55.27			83.4		65.4	
NHMW-20	1	380.5		90.3			54			99.1	85.6		
NHMW-15	1	382.5		93.7			54.6			99.5	90.4		
NHMW	1	383		94.6			63			98	89.5	68.3	
NHMW-31	2	384		98.6			54.6			86.5	84.2	39.4	

No.	Side	gl	pl	pb	pd	sd	db	bt	bda	hpat	dpa	bpc	dc
NHMW	2	385		91.5			60.08			99	85	65.3	
NHMW-1	2	388		87.6			54.6			101.5	84.05	69.2	
NHMW-21	2	389		89.5			54.4			92.1	81.06	70.2	
NHMW	2	391		84.95			55.1			87.4	77.6	61.3	
KJ-219	1	391.76		89.72			58.14			88.52	85.3	75	
NHMW-45	2	392		87.6									
NHMW-11	1	393.5		89.7			61.2			97.1	89.7	73.67	
NHMW-4	2	393.5		84.8			51			89	77.8	60.1	
NHMW	2	394		96.9			58			95.5	87.4		
NMLj-113-1	2	395		97.9			56.3					63.4	
NHMW-25	2	396					54			93			
KJ-76	1	399.15		93.86			57.7			97.5	86.6	70.9	
KJ-181	1	404.57		92.2			54.76			90	81.8	69.7	
IPUW	1	406.98		90.86			60.54			90.5	76	71.53	
NHMW-44	2	408		90.2			60.5			98	82	71	
NMLj-113-1	1	425		96.1			60.3			104.2	97	75.2	
FEMUR													
NHMW-10	2	364.5	345	93.7		36.6	80.6						46.3
KJ-136		366.48				27.52							
NHMW-11	2	367	337	97.5		39	81						47.5
NHMW-5	1	379	356	96.8		39.2	84						
NHMW-7	2	386	357	104.3		44.9	86.5						50.8
NHMW-2	1	396	368	110.5		45.4	95.9						
NHMW-3	1	406	384	113.8		42.6	96.9						54
NHMW		416		111			94						
NHMW-1	1	441	422	131			102.8						59.04
NHMW-4	1	463	430.15	137		50	108.5						62.9
NHMW-8	2	477	440	142		51.9	110.7						62.8
KJ-217	1	494.47	458.24	140.9		50.22	116.56						66.57
TIBIA													
NHMW-39	1	237.4		82.7		26.1							
NHMW-35	2	241.5		82.9		25.5	63.2		62.4				
NHMW-22	2	246.5				24.6							
NHMW-28	1	250.6				28.8	66.8		65				
NHMW-27	1	251.4		85.8		28.5	66.4		66.1				
NHMW-37	1	256.4		83.5		28.4	70.4		66.8				
NHMW-41	1	261.5		89.9		27.7	72.2		69.2				
KJ-187	2	262.43		88.68		30.87	68.78		65.89				
NHMW-46	2	263.5				29.6							
NHMW-14	1	265.2		87.4		27.7							
IPUW	2	265.84		88.89		32.22	70.69		62.7				
NHMW-19	2	266.8		91.2		34	74.4		69.2				
NHMW-50	2	267.3				31.3	68.2		67.9				
NHMW-15	2	267.4		88.6		29.3	72.8		65.7				
NHMW-5	2	267.7		90.9		32.1							
NHMW-49	1	270.2				31.1	70.5		70				
NHMW-12	2	271.2				31.3	70.5		65.3				

No.	Side	gl	pl	pb	pd	sd	db	bt	bda	hpat	dpa	bpc	dc
NHMW-21	1	271.8				31.4	72		66.8				
NHMW-25	1	272.2				28.2	68.1		60.9				
NHMW-16	2	273.1				30.9	69						
NHMW-20	2	273.3		92.6		30.9	72.5		69.1				
NHMW-34	2	273.6				34	72.4		69.4				
NHMW-3	1	275.5		91.1		28.4	74.3		61				
NHMW-45	1	275.9		95		32	71.6		70.4				
NHMW-40	2	277				30.2							
NHMW-13	2	278.7		94.5		34.1	77.5		74.4				
NHMW-44	2	279.1		92.5		30.5	70.8		70.8				
NHMW-2	1	281.4		90.45		31	71.4		60.2				
NHMW-29	1	282.3		99.2		34.3	76.7		71.4				
NHMW-1	1	283.1		104.3		35.3	83.1		67				
NHMW-47	1	290.9		108.7		38.2	86.3		80.4				
NHMW-10	2	300.3		104		36.7	84.8		80.5				
NHMW-7	1	301.27		106.3		35.4							
NHMW-18	2	301.4				33.12	81.8						
NHMW-8	2	301.8		103		40.1	88.7		79.3				
NHMW-36	1	304.5		104.6		23.4	76.8		71.8				
NHMW-11	1	309.3		104.9		33.2	80		77.9				
KJ-181	2	309.9		112.73		36.32	87.03		78.87				
NHMW-48	1	312.6		113.4		31.2							
NHMW-30	1	313.5				34.6	85.2		80.3				
NHMW-33	2	315				38.2	81						
NHMW-9	1	318.6		109.9		39	83.4		84.9				
NHMW-38	1	319.8		109		37.4	81		82.6				
NHMW-4	2	340.4		114		37	91.2		83				
FIBULA													
NHMW	2	225		26.7			31.2						
NHMW	1	230.0		21.6			27.2						
NHMW	1	230.0		22.0			29.4						
NHMW	1	233					28.1						
NHMW	2	235					30.7						
KJ-210	1	241.55					26.7						
NHMW	2	243		26			29.5						
NHMW	1	245.0		26.3			30.3						
NHMW	1	257		28.54			34.4						
NHMW	1	260		27.4			33.9						
NHMW	1	265		31.2			35.1						
NHMW	2	270					35.4						
NHMW	2	275		31.4			30.1						
KJ-6	1	299.2		31.8			41.3						

The Age and Sex Structure of the Cave Bear Population from Križna jama (Slovenia)

by

Irena Debeljak [1)]

Debeljak, I., 2014. The Age and Sex Structure of the Cave Bear Population from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:97 – 108, Wien.

Zusammenfassung

Für 28 Höhlenbären, die in der Križna jama gestorben sind, wurde das Sterbealter auf der Basis aller d_4 und M_1 bestimmt. Das Ergebnis zeigt einen vergleichsweise geringen Anteil an Jungtieren (32,1%) und einen relativ großen Anteil (28,6%) an senilen Individuen. Die Anwesenheit von Jungen unter einem Alter von drei Monaten zeigt, dass die Bärinnen die Križna jama auch als Wochenstube gebraucht haben um ihre Jungen zur Zeit des Winterschlafes zur Welt zu bringen. Das höchste, durch Zählung der Zementanwachslinien bestimmte Alter wies ein seniles Männchen auf, das 28 Jahre erreichte. Das zeigt, dass die Lebensspanne des Höhlenbären in etwa der des rezenten Braunbären entsprochen hat.
Die Bestimmung der Jahreszeit zum Todeseintritt wurde für 10 jüngere Individuen anhand der Zahnentwicklung und der letzten Zementanwachslinie durchgeführt. Die Mehrzahl der Todesfälle ist im Winter, also während der Zeit der Überwinterung, eingetreten. Es besteht auch die Möglichkeit, dass einige Bären die Höhle auch vor oder nach der Überwinterung aufgesucht haben und dabei gestorben sind. Die Geschlechterverhältnis wurde anhand von 67 Eckzähnen von Bären – die älter als 18 Monate waren – bestimmt. Mehr als 73% der Bären waren Männchen, das Verhältnis von Männchen zu Weibchen beträgt somit 2,72. Das zeigt, dass die Križna jama vor allem von adulten und senilen männlichen Bären zur Überwinterung genutzt wurde.

Schlüsselwörter: Križna jama, Höhlenbären, Zähne, Zahnzementanwachslinien, Bestimmung des individuellen Alters, Bestimmung der Jahreszeit beim Todeseintritt, Sex-Struktur

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Abstract

The age of 28 individual cave bears that died in Križna jama has been determined by the analysis of all left specimens of d_4 milk teeth and M_1 permanent teeth. The results show a relatively low proportion of juveniles (32.1%) and a large proportion of old animals (28.6%). The presence of individuals younger than 3 months indicates that females gave birth to cubs in Križna jama during hibernation. The oldest age was reached by a large male that lived for about 28 years, which was determined by counting cementum increments. The life span of the cave bear was therefore similar to that of the modern brown bear. Season at the time of death has been estimated for 10 younger individuals by the analysis of tooth development and by examining the last cementum increment. The majority of deaths occured in winter, during denning. It is possible, however, that some bears died in the cave before and shortly after the hibernation period. Sex structure has been studied on the sample of 67 canines of individuals older than 18 months. More than 73% of them belonged to males, which gives a male to female ratio of 2.72. It can be assumed that Križna jama was used as a winter den mostly by prime adult and old male bears.

Keywords: Križna jama, cave bear, teeth, cementum increments, individual age determination, season at death, sex structure

Izvleček

Na podlagi analize vseh levih primerkov mlečnih d_4 zob in stalnih M_1 zob je bila določena individualna starost 28 različnih osebkov jamskega medveda, ki so poginili v Križni jami. Rezultati kažejo relativno nizek delež mladičev (32,1%) in velik delež starih živali (28,6%). Prisotnost manj kot 3 mesece starih osebkov dokazuje, da so samice v Križni jami med hibernacijo kotile mladiče. Najvišjo starost je dosegel velik samec, ki je živel približno 28 let, kar je bilo ugotovljeno s štetjem cementnih prirastnic. Življenjska doba jamskih medvedov je bila torej

približno tako dolga kot pri današnjih rjavih medvedih. Za 10 mlajših osebkov je bilo mogoče oceniti sezono ob smrti, in sicer po analizi razvitosti zob ter s preiskavo zadnje cementne prirastnice. Večina živali je poginila pozimi. Možno pa je tudi, da so nekateri medvedi v jami poginili tudi že pred hibernacijo in v kratkem obdobju po hibernaciji. Spolna struktura je bila proučena na vzorcu 67 podočnikov več kot poldrugo leto starih osebkov. Od teh jih je več kot 73% pripadalo samcem, tako da razmerje samcev proti samicam znaša 2,72. Sklepamo lahko, da so Križno jamo kot zimski brlog večinoma uporabljali zreli odrasli in stari samci.
Ključne besede: Križna jama, jamski medved, zobje, cementne prirastnice, določanje individualne starosti, sezona smrti, spolna struktura

1. Introduction

The aim of this study was to determine the sex, individual age, and season at the time of death of cave bears from Križna jama. The studied material was found during excavations in 1999 and 2001 conducted by Prof. Vida Pohar (University of Ljubljana, Slovenia) and Prof. Gernot Rabeder (University of Vienna, Austria). This study is a part of the broad-based, still ongoing reasearch concerning the structure of cave bear populations from different Slovenian sites (Debeljak, 2002; 2004; 2007; 2011) with the purpose of acquiring new data on the biology, behaviour, ecology, and mortality of this extinct species. Križna jama is of special interest here because it represents a much larger and more complex cave system than the other Slovenian sites containing cave bear remains which have been examined thus far.

Križna jama is a more than 8 km long underground river cave, located in the karstic Notranjska region, north of the town Lož (SW Slovenia). Its altitude at the entrance is about 630 metres above sea level. Cave bear remains included in this study are of Middle Würmian age. Radiocarbon dating results constrain their ages between 47.000 and 32.000 years BP (Rabeder & Withalm, 2001; Pohar et al. 2002; Rabeder, 2009; Bosák et al., 2010; Rabeder et al., this volume). Cave bears from Križna jama are particularly large and belong to the highly evolved *Ursus ingressus* lineage (Rabeder & Hofreiter, 2004; Rabeder, 2009; this volume).

2. Sex Structure

Due to pronounced sexual dimorphism, a cave bear's sex can be determined from the dimensions of the canines (Koby, 1949; Kurtén, 1955). Thus, the sex ratio, i.e. the ratio of males to females in a cave bear site, can be estimated from the sample of all canines (isolated or still attached to the jawbones) of individuals older than 18 months. Canines of individuals less than 18 months old are unerupted teeth with no root, consisting only of a hollow crown, which is often damaged at the base and difficult to measure reliably. For this reason the canines of yearlings were not included in the analysed sample. The dimensions of upper and lower canines do not differ significantly and can be analysed together.
The results of measurements of the crown width (i.e. transverse diameter) of 44 well-preserved canines from Križna jama are presented in a histogram in Figure 1. As expected, there is clear bimodal distribution which allows us to reliably separate canines of males and females.

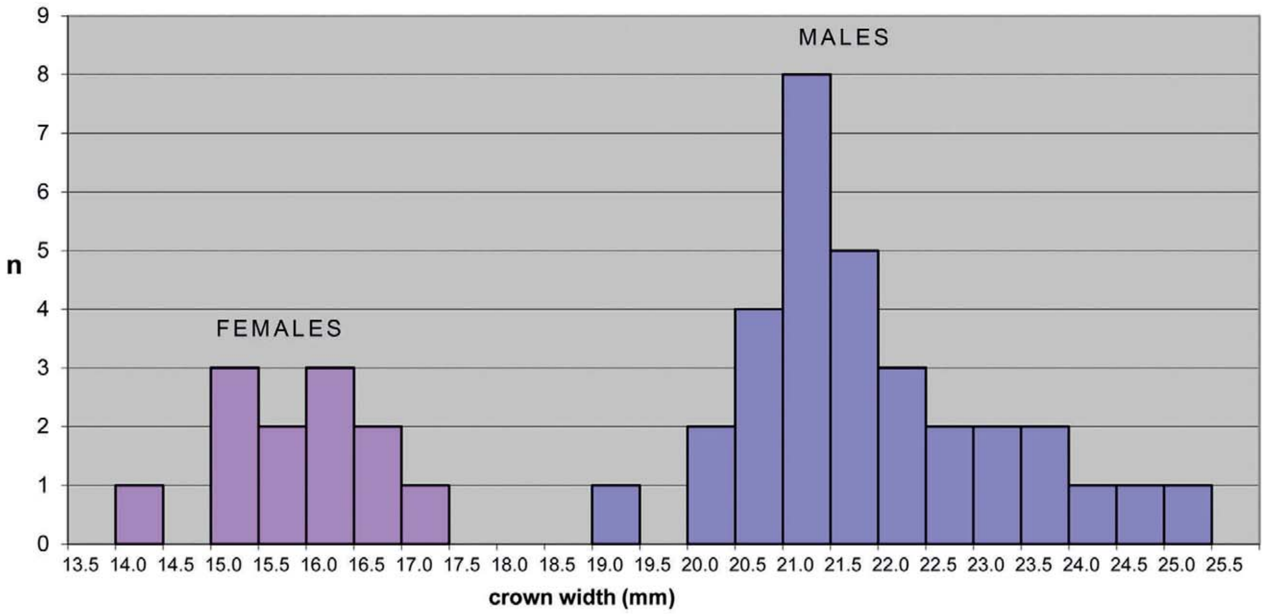

Figure 1: Histogram of the crown width of upper and lower canines (44 specimens) from Križna jama. Bimodal distribution indicates pronounced sexual dimorphism.

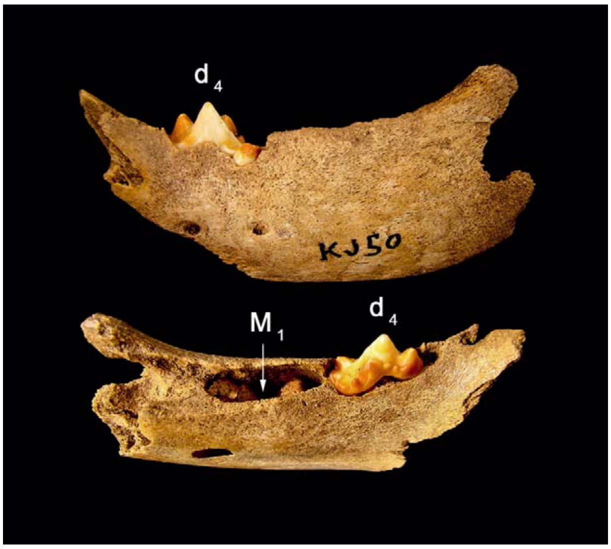

Figure 2: Left mandible (KJ 50) of a 2–3 month old cub from Križna jama. D_4 milk tooth is not fully erupted. The crown of permanent M_1 tooth is still completely encased in the jawbone. Buccal and linguo-occlusal views. Natural size.

The size difference between male and female canines is so obvious that sex can be identified from their overall dimensions, usually also in the case of specimens that are too worn or too damaged to be measured accurately. In this way, sex was determined for 67 canines altogether. Forty-nine of them (73.1%) belonged to males and only 18 (26.9%) to females. Male to female ratio is 2.72 – the cave bear population from Križna jama is therefore highly dominated by males. The same conclusion was drawn by Rabeder & Withalm (this volume). The prevalence of males in Križna jama is not surprising. It supports the assumption of Kurtén (1955) that large caves were chosen for denning mostly by males, whereas females prefered small caves with hidden entrances allowing them to protect their cubs from adult males.

Interestingly, the predominance of males is particularly pronounced in the group of canines with their root still widely open at the apex, that belonged to 2-4 year old animals, i.e. older juveniles and subadults. In the sample of 9 specimens, 8 belonged to males and only one to a female, which could indicate a higher mortality of males in this age group. A similar situation was observed in the sex structure of cave bear population from Mokriška jama (Debeljak, 2007). Also in modern bears, the age period of 2–4 years is more critical for males than females. Cubs are usually weaned at the age of two or three years, when their mothers chase them away or abandon them. Subadult females are better tolerated by adult females and are often allowed to stay in the same home range after weaning, while subadult males usually travel large distancies to find their own territory (Elowe & Dodge, 1989; Swenson et al., 1998; McLellan & Hovey, 2001). They can be overcompeted in the search for food or fall prey to adult males, who can be very aggressive towards subadult males. Intraspecific competition is enhanced by high population density and in case of shortage of available food (McCullough, 1981; Bunnel & Tait, 1981; Tietje et al., 1986; McNamee, 1997).

3. The Youngest Cubs

Neonates, i.e. infants that died in the first month after birth, cannot be studied on the basis of their teeth. Milk teeth developed to a sufficient degree and started to erupt only in the second or third month of life (Debeljak, 1997). Cubs that died at the age of 1–6 months are best represented by d_4 teeth, which are the largest milk teeth. Nevertheless, they are still quite small (Fig. 2) and usually overlooked during excavations if the sediment is not water-sieved. So far, only excavations in Divje babe I cave have yielded a considerably large sample. In the study of the Divje babe population structure, more than 900 specimens of left d_4 teeth were analysed (Debeljak, 2002). From Križna jama, however, only 5 specimens of left d_4 teeth (4 isolated and 1 in mandible) were available for the analysis (Table 1). The roots of three of them were completely resorbed – they were probably shed naturally during denning in the second winter. Therefore, they do not represent dead individuals. The remaining two specimens belonged to 2–3 month old cubs, which is another piece of evidence that females occasionally gave birth to cubs in Križna jama, although it was mostly occupied by adult males. Considering the fact that bears are usually born in January, these two cubs probably died in March or April, a month or two before they would have left the winter den with their mother. Possible causes of their death could have been disease or maternal abandonment, as observed in modern bears (Elowe & Dodge, 1989). Furthermore, they could have been killed by predators, or even more likely by an adult male cave bear. In all bear species, males practice infanticide either to make the female sexually receptive or simply for the purpose of consumption (McCullough, 1981; Tietje et al., 1986; LeCount, 1987; Miller, 1990; Craighead et al., 1995; Derocher & Wiig, 1999; Wittenberg & Wendzelides, 2000).

A well preserved mandible (KJ 50) of approximately 2 month old cub from Križna jama with the erupting d_4 tooth is shown in Figure 2. Individual age was determined by using data conserning the ontogenetic development of teeth in different bear species (Pohle, 1923; Dittrich, 1960; Marks & Erickson, 1966; Debeljak, 1997).

4. Yearlings and 2-year-olds

Individuals older than 6 months are usually best represented by M_1 teeth, which are the first permanent teeth to develop and erupt in bears (Dittrich, 1960). As in the other Slovenian localities, left lower M_1 teeth were chosen for the study of age structure of the cave bear population from Križna jama. In the sample of 26 left M_1

teeth, 7 specimens belonged to yearlings and 2-year-olds (Table 1). The thickness of their root wall was measured in cross sections about 7 mm below the crown, as shown in Figure 3. Furthermore, the relative width of the anterior and posterior root canal was determined for each specimen (Table 1: r. ant., r. post.). It is defined as the diameter of the tooth root divided by the diameter of the root canal (Fig. 3: AB/CD). In juveniles, all data of this sort can be used as a criterion to assess individual age and season at the time of death (Debeljak, 2002; 2004; 2007; 2011).
M_1 teeth erupted during the first summer at the age of about 5 months. Initially, the teeth were completely hollow, then gradually became filled with secondary dentin during the first four years of life, until only a narrow canal remained in the centre of their roots (see e.g. Debeljak, 2011, Plate 1, Figs. 2a–c, 3a). For comparison: M_1 root wall is about 1.25 mm thick in yearlings, and 2.5 mm thick in 2-year-olds. Interestingly, in a large sample of M_1 teeth from Divje babe I, Mokriška jama, Potočka zijalka and Ajdovska jama, there are very few specimens with 1.75–2.25 mm thick root wall, because at this stage of ontogenetic development, bears were usually absent from the caves. In Križna jama, however, 4 such specimens were found, which is a large number, considering the small sample size.
This unusual situation is clearly observable in the scatter plot of relative width of anterior and posterior root canal in M_1 teeth from different Slovenian cave bear sites (Fig. 4). Specimens from Križna jama are marked with red dots. A circle shows the approximate position of two broken specimens (KJ 50a and KJ 51) where only a single root canal could be measured (Table 1). The group of yearlings (black dots) is clearly separated from the group of 2-year-olds (grey dots) by a prominent gap in distribution. This proves that the mortality was not distributed evenly throughout the year. The vast majority of bears, whose remains have been recovered from Divje babe I, Mokriška jama, Potočka zijalka, and Ajdovska jama, died during the denning period, from October to May or June. At the height of the summer season, on the other hand, there was literally no mortality. The four specimens from Križna jama mentioned above belong to the upper range of yearlings and the lowermost range of 2-year olds, and there is another specimen in the lowermost range of yearlings. This could indicate that cave bears stayed in Križna jama somewhat longer in the spring and started denning somewhat earlier than average. However, the analysed sample is too small to allow us to draw any reliable conclusions of this sort. Determination of the season at the time death by dental cementum analysis, which will be described below, is unfortunately very difficult to apply in the case of animals younger than 2 years. The results are not completely reliable, but it seems quite possible that the two yearlings, marked as KJ 184a and KJ 6, died already in the post-hibernation period and that specimen KJ 50a belonged to a less than 2 year old juvenile that died before the beginning of hibernation (Table 1).
Like in the previous age group, possible causes of death in 1–2 year old juveniles could be adult male aggression, attacks by lions, hyenas, or wolf packs, premature maternal abandonement, and malnutrition. When their fat reserves are not adequate, bears are unable to survive 6 or more months without food. Cases of yearlings dying in their den during particularly long winters have also been reported for modern bears (Schoen et al., 1987; Rogers, 1981; 1987).

5. Subadults and Prime Adults

In subadult and adult bears, individual age can be determined by counting dental cementum increments. This is the most reliable and objective method that has long been used routinelly in modern bears, as well (Rausch, 1961; Mundy & Fuller, 1964; Marks & Erickson, 1966; Hensel & Sorenson, 1980; Harshyne et al., 1998; Calvert & Ramsay, 1998). Cementum is bone-like tissue that is continuously deposited on the surface

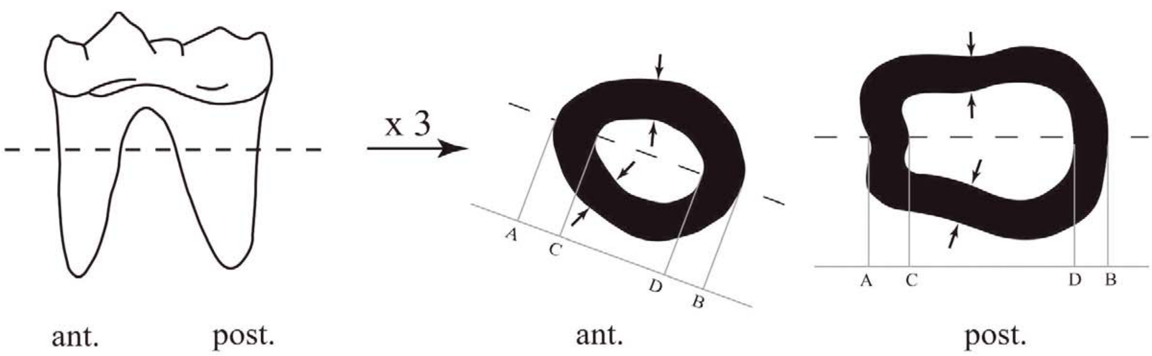

Figure 3: Sketch of M_1 tooth in natural size, and magnified cross section through the anterior and posterior root at the age of 1 year. Arrows indicate where the thickness of root wall can be measured. AB: diameter of root, CD: diameter of root canal.

LEFT LOWER D_4:								
Inv. no.	Description					Stage	Individual age	Season at death
mand. KJ 50	erupting					1–2	2 months	„winter“
KJ 51	slightly open root apices					2	2–3 months	„winter“
KJ 54	resorbed root – shed milk tooth					6		
KJ 62	resorbed root – shed milk tooth					6		
KJ 185	resorbed root – shed milk tooth					6		
LEFT LOWER M_1:								
Inv. no.	Length (mm)	Width (mm)	Root wall (mm)	R. ant.	R. post.	Tooth wear	Individual age	Season at death
KJ 12a	30.7	15.8	0.75–1		1.22	II	1 year	early „winter“
KJ 118	27.6	13.4	1–1.25	1.46	1.32	II	1 year	„winter“
KJ 184a	32.5	15.7	1.75–2	1,72	1.45	II–III	1–1.5 years	late „winter“ – early „summer“
KJ 6	28.7	13.9	1.75–2	1.74	1.48	II	1–1.5 years	late „winter“ – early „summer“
KJ 50a		14.3	2–2.25		1.66	II–III	1.5–2 years	late „summer“ – early „winter“
KJ 51			2–2.25	1.98		II–III	2 years	early „winter“
KJ 12b			~ 2.5			II–III	2 years	
KJ 50/1	31.7	16.0	~ 3	4.13	2.99	II–III	3 years	early „winter“
KJ 184b	29.6	14.3	~ 3.5	5.20	3.75	II–III	3–4 years	
KJ 145	29.3	14.2				V	8 years	„winter“
KJ 50/4						VI	13–15 years	
KJ 50/3	~ 31.2	15.6				VI	16–18 years	
KJ 62	~ 29.3	~ 14.4				VI	17–19 years	
KJ 11/1	~ 32.7	~ 16.5				VII	18–20 years	
KJ 168	~ 29.8	~ 14.5				VII–VIII	18–20 years	
KJ 210		~ 14.5				VII	20–22 years	
KJ 50b						VII–VIII	20–22 years	
KJ 134	~ 29.1	~ 14.1				VIII	22–24 years	
KJ 146	~ 29.1	~ 14.2				VIII	23–25 years	
KJ 50/5	~ 29.3	~ 14.6				VIII–IX	24–26 years	
KJ 11	~ 30.0	~ 14.4				IX	24–26 years	
KJ 119	~ 32.9	~ 16.9				IX	26–30 years	
mand. KJ 89						V	~ 10 years	
mand. KJ						V	~ 10 years	
mand. KJ 231						V–VI	~ 10–15 years	
mand. KJ 001						IX	~ 25 years	

Table 1: Individual age estimations and other data for left lower d_4 teeth (5 specimens: 4 isolated, 1 in mandible) and left lower M_1 teeth (26 specimens: 22 isolated, 4 in mandible) from Križna jama. „Winter“ season is the period when bears stayed in their winter den – from late autumn to early spring. The remainder of the year is considered as „summer“.

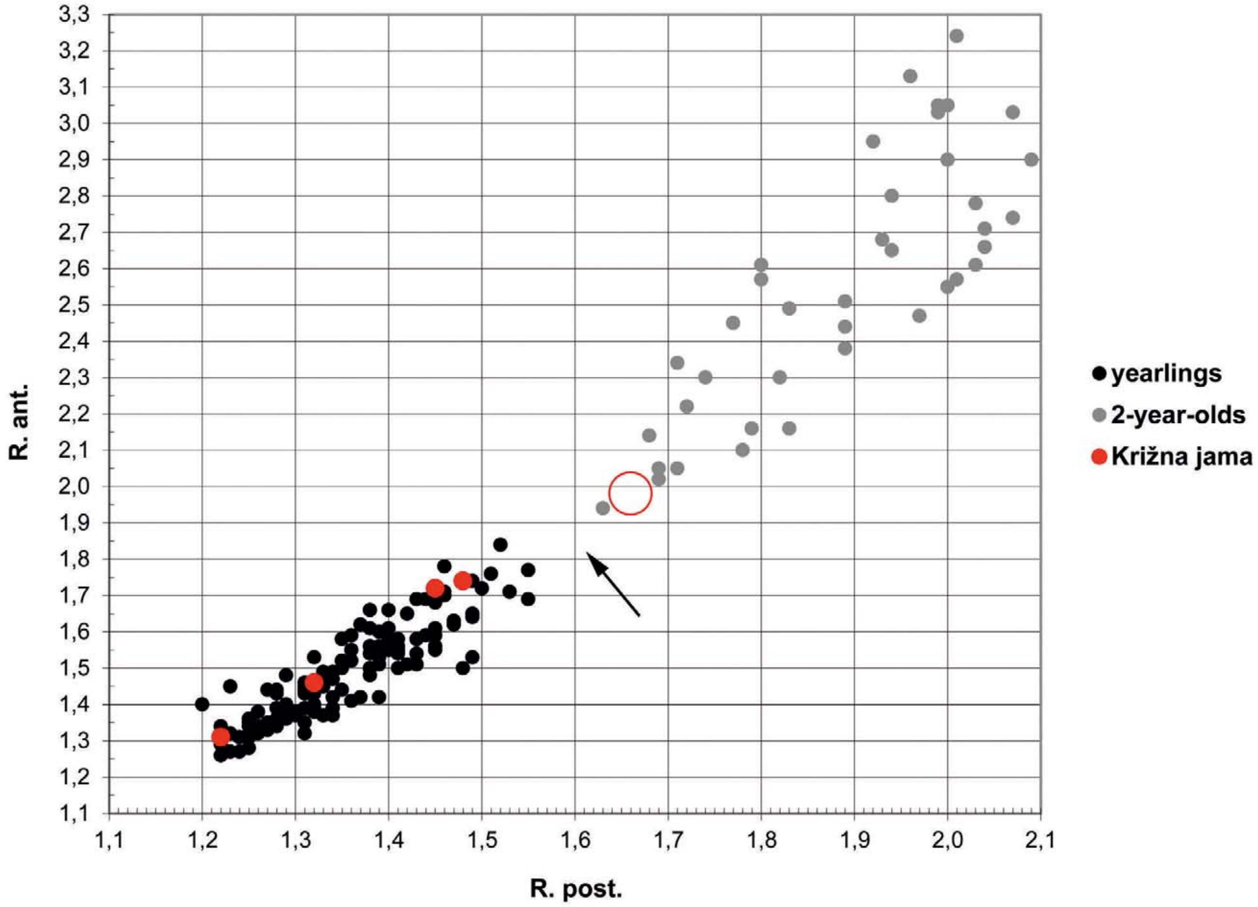

Figure 4: Scatter plot of the relative width of pulp canal in the posterior and anterior root (r. post., r. ant.) showing the degree of root development in M_1 teeth of yearlings (black dots) and 2-year-olds (grey dots) from different Slovenian sites (Divje babe I, Mokriška jama, Potočka zijalka, and Ajdovska jama). Four specimens of yearlings from Križna jama are marked with red dots. Red circle indicates the approximate position of two Križna jama specimens in which only the anterior or posterior root is preserved. An arrow points to hiatus in distribution.

of tooth roots throughout the entire life. It is composed of the so-called „winter“ and „summer“ layers, similar to growth rings in trees. The first 5–8 annuli are generally much wider than the rest (Fig. 5). Season at the time of death can be estimated in well-preserved specimens of subadults and younger adults by examining the last (outermost) cementum increment. In a 3-year old specimen depicted in Figure 6, for example, a dark „winter“ increment just started to form, indicating that death occurred early in the denning period. In bears older than about 8 years, however, season at death usually cannot be determined, because of progressively thinner and tightly packed cementum increments. No „summer“ and „winter“ increments can be distinguished in cementum at an older age, only fine reversal lines between annual layers, that enable us to estimate individual age in years (for more details see Debeljak, 2011).

Dental cementum has been examined in all 22 isolated specimens of left M_1 teeth from Križna jama. For this purpose, tooth roots were cut transversely about 7 mm below the crown. Thin sections and etched/coloured ground sections were prepared as described by Debeljak (1996; 2000). Ground sections were etched with 10–12% orthophosphoric acid (H_3PO_4) for 3–5 minutes, and then coloured with approximately 0.5% aqueous solution of gentian violet. During this process tooth crowns were always left intact. The teeth still attached in mandibles were not cut, and their cementum was not examined, because it would be impossible to extract them without damaging the jawbone. Individual age was roughly estimated for 4 such specimens by comparing their crown wear patterns to the teeth of known individual age.

Individual age estimations and other collected data for all studied specimens are presented in Table 1. Measurements of crown length and width were taken when possible. Furthermore, occlusal wear was recorded according to the scheme of nine stages (I–IX) proposed by Stiner (1994; 1998). Two M_1 specimens out of 26 belonged to 3–4 year old immature bears (subadults), that probably already lost the company and protection of their mothers. As discussed in Section 2, bears, especially males, are very vulnerable at this age. Brown bear females usually

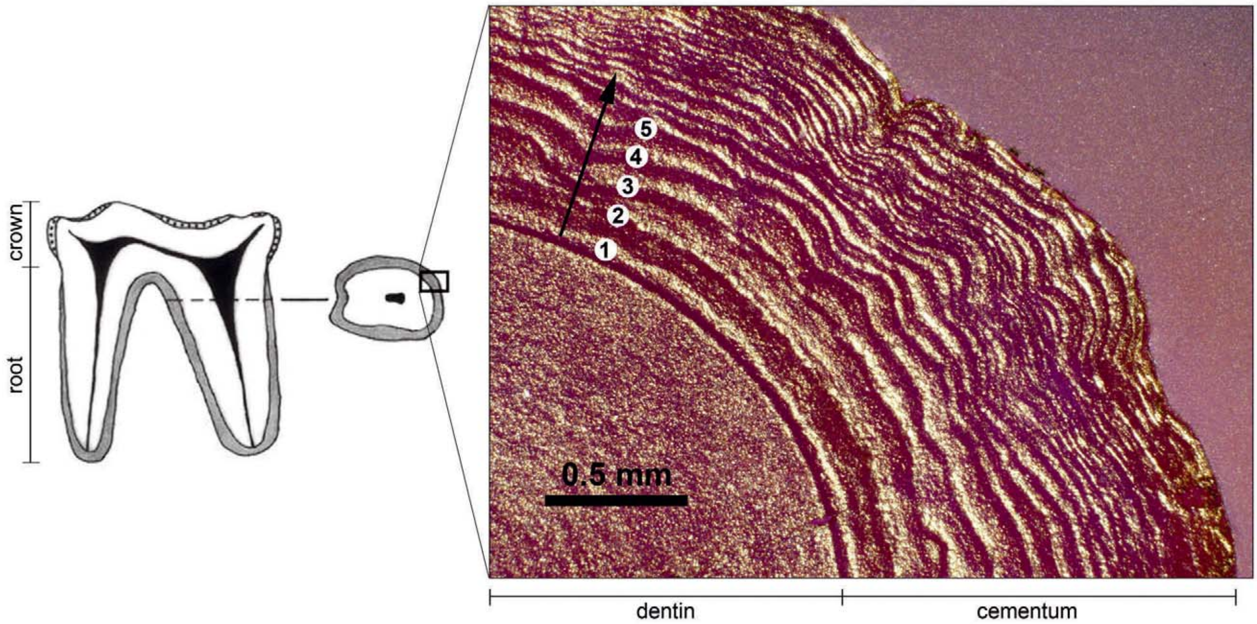

Figure 5: Sketch of M_1 tooth in longitudinal section and cross section through the posterior root in natural size. Pulp cavity: black; dentin: white; cementum: grey. Enlarged detail of etched and coloured cross section of a specimen from Križna jama (KJ 134) is shown on the right. An arrow indicates direction of cementum deposition. The first five cementum annuli are marked with numbers. Individual age estimation: 22–24 years.

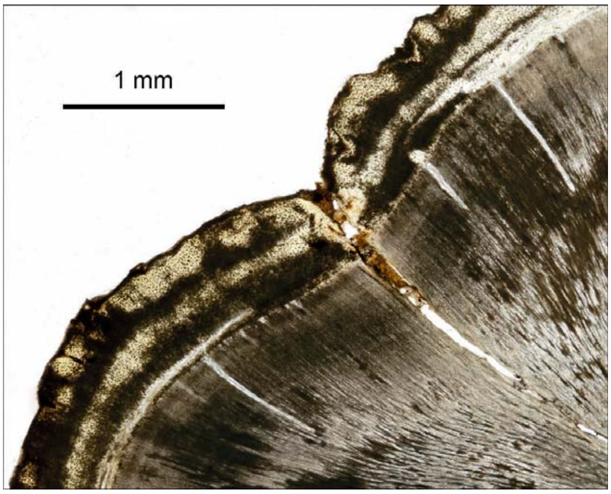

Figure 6: Dental cementum in the thin section of M_1 specimen (KJ 50/1) from Križna jama. Individual age: 3 years. Season at death: early „winter“ (early denning period).

abandon their young at the age of about 2 and a half years; sometimes a year earlier or later (Bunnel & Tait, 1981; Craighead et al., 1995). Cave bears were probably not different in this respect.

The 9 M_1 specimens from Križna jama belonged to 8–19 year old animals, i.e. prime adults (Table 1). Undoubtedly, these were cave bears at their prime. Modern bears at this age are usually quite fit and have literally no enemies other than man (e.g. McNamee, 1997). So why did adult bears die in Križna jama? Diedrich (2011a, b) suggested that two species: Upper Pleistocene hyena (*Crocuta crocuta spelaea*) and cave lion (*Panthera leo spelaea*) predated on hibernating cave bears. There is evidence of both in Križna jama. Diedrich pointed out that predation stress of lions and hyenas onto cave bears seems to be one of the main reasons why cave bears hibernated in caves as deep as possible, and were climbing through dangerous and difficult passages in complete darkness to get to the safest place. Also in the case of Križna jama, cave bears hibernated several hundred metres deep inside the cave.

6. Old Bears

Modern brown bears are considered to be *old* after the age of 20 years (Craighead et al., 1995). The average life span of brown, polar and black bear is 20–25 years, but under favourable conditions, they can live up to 30 years in the wild (Bunnel & Tait, 1981; Derocher, 2000). It has long been believed, however, that cave bears could not have lived that long. Soergel (1940) was probably the first who assumed that the longevity of the cave bear was considerably reduced, because their teeth wore down more rapidly due to their exclusive herbivore diet, in comparison to omnivorous brown bear. The exposure of pulp cavities led to infections and caused serious dental pathologies that can be frequently observed in cave bear jawbones. Undoubtedly, cave bears could not have gained enough weight before the winter without an efficient feeding apparatus. It can be imagined that this was really a matter of life or death. For this reason, Kurtén (1958; 1976) expressed doubt that any cave bear lived beyond about

20 years of age. He assumed that the maximum life span was only 15–20 years.
However, analyses of dental cementum in cave bear teeth from Divje babe I and Mokriška jama indicated that cave bears could have lived much longer than previously thought (Debeljak, 2007). Accordingly, age determinations of M_1 specimens from Križna jama (Table 1) indicate a moderate increase in the mortality rate not earlier than around the age of 20. In the sample of 26 left M_1 teeth from Križna jama, there are 8 specimens that belonged to cave bears older than 20 years. Mortality in this age group can be attributed to senescence-related malnutrition and vulnerability. M_1 tooth crowns are completely worn only in specimens that belonged to cave bears approximately 25 year old (Table 1; wear stage IX). The oldest age recorded is approximately 28 years, as determined by counting cementum increments in the specimen KJ 118. Interestingly, this is actually the largest M_1 tooth in the sample from Križna jama, which can be quite reliably attributed to a large male. All the evidence indicates that the life span of the cave bear was similar to that of the modern bear species.

7. Age Structure

The age of 28 individual cave bears that died in Križna jama has been determined by the analysis of all left specimens of d_4 milk teeth and M_1 permanent teeth. Only left specimens were taken into consideration to prevent the doubling of data for the same individual. In Figure 7 the frequencies of d_4 and M_1 teeth in different age groups are presented. Figure 8 shows proportions and percentages of juveniles (less than 3 year old animals), subadults (3–4 year old animals), prime adults (5–20 year old animals), and old adults (animals older than 20 years).
The most striking result is the high proportion of old adults (28.6%). The ratio between prime adults and old adults is almost 1:1, the lowest in Slovenian localities that have been studied thus far. More than 30% of all M_1 teeth belonged to animals older than 20 years. For comparison, in the sample of M_1 teeth from Divje babe I, there are only 3.4% of such specimens, from Potočka zijalka 9.6%, and from Mokriška jama 16% (Debeljak, 2002; 2004; 2007). Very low proportion of heavily worn teeth has been reported from many other localities, as well (e.g. Rabeder, 1992; Grandal d'Anglade & Vidal Romaní, 1997; Weinstock, 1999; 2000; 2001; Pacher, 2000).
Modern bears only die in their denning place on rare occasions (Van Daele et al., 1990). If their fat reserves are depleted too early, starving animals leave their den and eventually die somewhere else in case they do not find any food (McNamee, 1997). Such behavior could explain the relatively low proportion of old animals in the cave bear localities mentioned above as well. However, Križna jama is a very large cave with long passages, and it seems that it was more common for old, weakened animals to stay in their denning place until their death. One could say that Križna jama was a sort of graveyard for old bears.

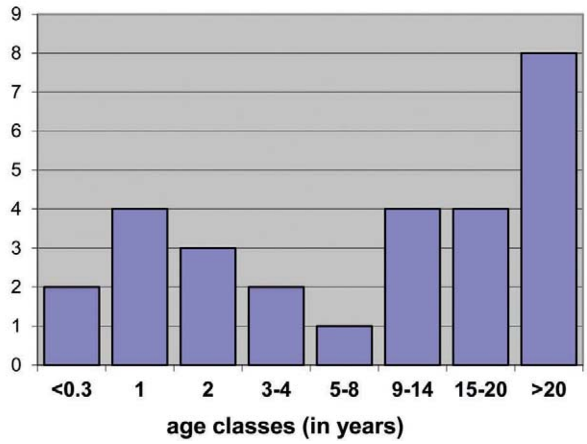

Figure 7: Number of individuals in different age groups (based on 2 left specimens of d_4 and 26 left specimens of M_1).

Another fact has to be taken into consideration when explaining the high proportion of old adults in Križna jama: the number of juveniles is disproportionally low.
The number of the youngest, less than 3 month old cubs was expected to be low for the simple reason that milk teeth (d_4) were largely overlooked during the excavations due to their small size. More surprising is the relatively low proportion of yearlings – only about 15%. For comparison: in Divje babe I, Potočka zijalka and Ajdovska jama more than a half of all M_1 specimens belonged to yearlings (Debeljak, 2002; 2004; 2011). Only in Mokriška jama, the proportion of yearlings is also relatively low, but still exceeds 20% (Debeljak, 2007). The low number of yearlings could partly be explained as the result of male predominance in Križna jama and Mokriška jama. It can be imagined that females with their young avoided caves where adult males would usually hibernate. However, adult males were predominant in Potočka zijalka as well, but the proportion of yearlings was still very high (52.8%). Although juveniles hibernated in Potočka zijalka less frequently than adult males, their mortality rate was much higher, hence their large proportion in the thanatocenosis. Juvenile-dominated age structure has been determined in some other localities where preponderence of males has been established as well (Weinstock, 2000; Quiles & Monchot, 2004). Therefore, there must be another reason for the low proportion of yearlings in Križna jama.
The ratio of yearlings to 2-year olds is only 1.33 (4:3) in Križna jama, and 1.42 (27:19) in Mokriška jama. In Potočka zijalka, on the other hand, it is 7.83 (47:6), and in Divje babe (layers 2–10) 6.97 (223:32). There is no logical explanation for such discrepancies between these localities other than taphonomy. As already mentioned in Section 4, the M_1 teeth of yearlings are hollow and have considerably thinner root wall than the same teeth of 2-year-olds. For this reason, teeth of yearlings are much more fragile and prone to destruction. The mortality of yearlings was undoubtedly much higher than the mortality of 2-year-olds.

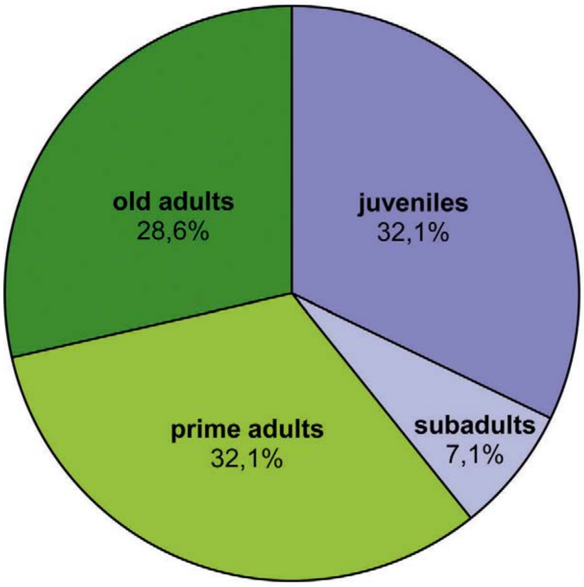

Figure 8: Age structure of the Križna jama cave bear population: pie chart with proportions of different age groups, based on the analysis of d_4 and M_1 teeth.

The ratio of yearlings to 2-year-olds in Potočka zijalka and Divje babe is certainly closer to the actual situation and is a better representation of the original thanatocenosis than the one observed in Mokriška jama and Križna jama. It can be assumed that teeth of yearlings are considerably underrepresented in these two caves due to less favourable taphonomic conditions. This is supported by the fact that the cave bear teeth from Križna jama are generally in a much worse state of preservation than teeth from Divje babe or Potočka zijalka. Dental tissues are heavily corroded. Cave bear remains in Križna jama were often affected by flood water and were all relocated from their original position (Rabeder & Withalm, 2012).
More fragile skeletal parts (teeth of less than 18 months old individuals) suffered a much higher degree of taphonomic losses during various destructive processes than the mechanically more resistant ones (M_1 teeth of 2-year-olds or older bears). The conditions were more favourable when cave bear remains were buried rapidly in the sediment due to the high sedimentation rate, and remained there relatively undisturbed. This was probably also the case in Potočka zijalka (Debeljak, 2004). In my opinion, differences in the proportion of juveniles between various cave bear localities were mainly caused by different taphonomic conditions. The age structure of the original thanatocenosis was undoubtedly influenced by the sex structure of the cave bear population that visited the cave and also by different paleoecological conditions. However, this was later largely blurred by destructive taphonomic processes that affected the remains of various age groups to a different degree.
Data from different cave bear localities can be compared in Figure 9. The proportions of three main age groups in the sample of M_1 teeth are presented in tripolar plot as proposed by Stiner (1994; 1998). Subadults are included in the group of juveniles here. Križna jama, Mokriška jama and Potočka zijalka were populated by a large, highly evolved *Ursus ingressus*, and all three were most frequently used by adult males. However, the age structure of cave bear remains varies considerably between the three localities. Križna jama (red dot) is virtually in the middle of the triangle in Figure 9. This is in no way typical for a cave bear site. The proportion of old adults is larger than normal. The mortality pattern is almost old-dominated. Furthermore, the proportion of juveniles is remarkably low. The age structure of well-preserved cave bear remains from Potočka zijalka (grey dot), on the other hand, is clearly juvenile-dominated. Only the age structure of cave bear remains from Mokriška jama (black dot) corresponds to the classical U-shaped or ‚normal non-violent attrition' mortality pattern. Age structure of cave bear remains indicates that the taphonomic conditions in Križna jama were generally the least favourable for the preservation of fossil material of all Slovenian cave bear sites studied so far.

8. Conclusions

Cave bear canines from Križna jama display pronounced sexual size dimorphism which allows clear separation of male and female specimens. Sex structure has been studied on the sample of 67 canines of individuals older than 18 months. More than 73% of them belonged to males. It can be assumed that Križna jama was used as a winter den mostly by adult males.
The predominance of males is particularly notable in the age group of 2–4 year old, still immature bears which indicates that the period of weaning was more critical for males than females. This is in accordance with observations in modern bears.
The age of 28 individual cave bears that died in Križna jama has been determined by the analysis of all left specimens of d_4 milk teeth and M_1 permanent teeth. The presence of two 2–3 month old cubs indicates that females gave birth to cubs in Križna jama during hibernation. The oldest age recorded was reached by a large male that lived for about 28 years. It was determined by counting cementum increments. Another 7 bears from Križna jama lived longer than 20 years. This contradicts the still widespread opinion that cave bears could not reach more than 15–20 years. Data from Križna jama indicate that the life span of the cave bear was not reduced because of its diet. The longevity of the cave bear was basically the same as in modern bears.
The large number of old animals in Križna jama indicates that it was more common for old, weakened animals to stay in their denning place until death than in the majority of other, smaller caves. Possible causes of mortality in juveniles were premature maternal abandonement, malnutrition, injuries, disease, predator attacks and particularly aggression of adult male cave bears. Adult animals could have been killed during the hibernation by cave lions or hyenas.

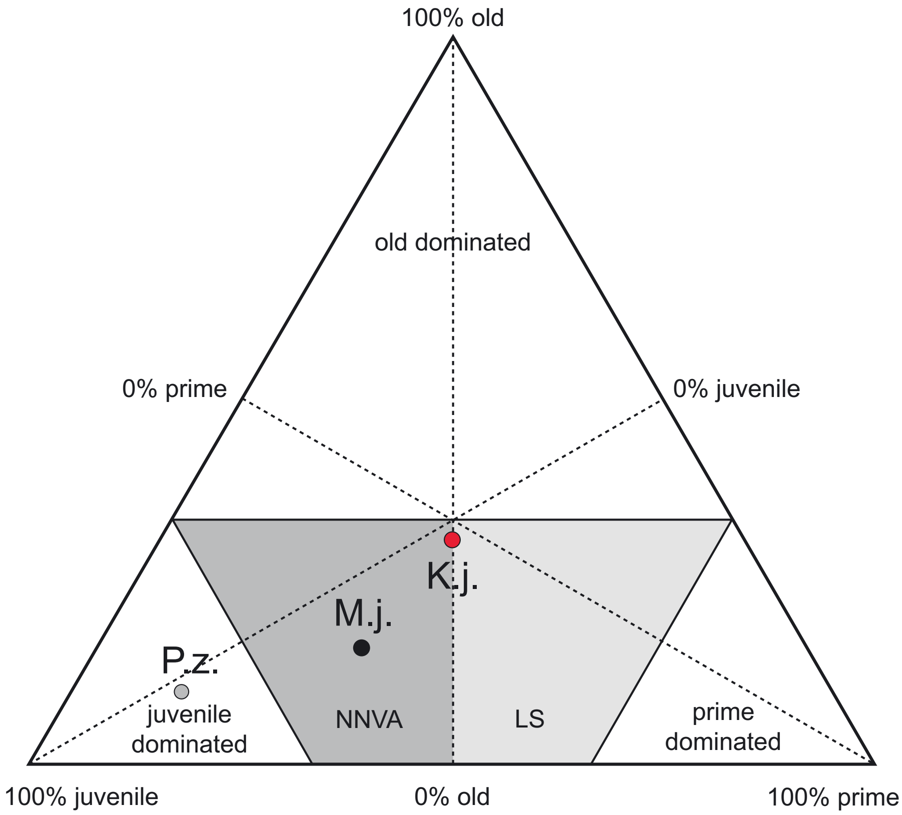

Figure 9: Tripolar plot denoting the proportions of three main age groups in samples of left M_1 teeth from Križna jama (red dot), Mokriška jama (black dot) and Potočka zijalka (grey dot). After Stiner (1990; 1994; 1998); dark grey field represents U-shaped or NNVA (normal non-violent attrition) mortality pattern, and light grey LS (living structure) pattern.

Season at the time of death has been estimated for 10 younger individuals by the analysis of tooth development and by examining the last cementum increment when possible. The majority of deaths occured in the winter, during denning. It is possible, however, that some bears died in the cave before or shortly after the hibernation period as well.

The age structure of cave bear remains from Križna jama is not typical for a cave bear site. The proportion of old bears is unusually large (28.6%), while the proportion of juveniles is remarkably low (32.1%). Only about 15% of all M_1 teeth belonged to yearlings, in comparison to some other Slovenian sites where specimens of this age group absolutely prevail with more than a 50% share. This could be partly explained as the result of male predominance in Križna jama.

Furthermore, it can be assumed that differences in the proportion of juveniles between various cave bear localities were mainly caused by different taphonomic conditions. The age structure of the original thanatocenosis was undoubtedly influenced by the sex structure of the cave bear population that visited the cave and also by different paleoecological conditions. However, this was later largely blurred by destructive taphonomic processes that affected the remains of various age groups to a different degree. Very low proportion of hollow, fragile teeth of animals younger than 18 months reflects unfavourable preservational conditions in Križna jama. Cave bear remains were badly affected by flood water. Its effect can also be observed in severely damaged dental tissues.

9. Acknowledgements

I am very grateful to Vida Pohar and Gernot Rabeder for providing the specimens from Križna jama, which enabled this study. Kata Cvetko-Barić helped with the laboratory preparation of the material. Miloš Bartol reviewed the English text. This article would not be published without help of Martina Pacher, Vida Pohar and Gerhard Withalm, the editors of the Križna jama monograph. Many thanks for their patience and support.

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Sexual Dimorphism and Sex-Ratio of Cave Bears from Križna jama (Slovenia)

by

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Rabeder, G. & Withalm, G., 2014. Sexual Dimorphism and Sex-Ratio of Cave Bears from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:109 – 116, Wien.

Zusammenfassung

Nicht nur an den Caninen sondern an fast allen Skelettelementen, die mit einer gewissen Häufigkeit überliefert worden sind, ist ein sexing möglich. Es ergab sich allgemein eine deutliche Dominanz der männlichen Tiere. Es hat sich gezeigt, dass die Möglichkeit der geschlechtsbedingten Clusterbildung vom Sexualdimorphismus-Index (sdi) abhängig ist. Im Vergleich zu anderen Höhlenbärenfaunen werden eventuelle Korrelationen zwischen Sexualdimorphismus, Sexratio, Höhenlage der Fundstellen und taxonomischer Zugehörigkeit diskutiert.
Schlüsselwörter: Sexing, sex-dimorphism-index, Dominanz der Männchen, Križna jama, Slowenien

Summary

Despite former assumptions that sexing is only possible with canines, it appears that nearly every skeletal element is usable for sexing, if only the number is big enough. In Križna jama there is a clearly visible dominance of male individuals. The possibility of sex-related clustering is depending on the sex-dimorphism-index (sdi). Possible correlations between sex-dimorphism, sex ratio, altitude of the site and taxonomic attribution are discussed by means of comparison with other cave bear faunas.
Keywords: Sexing, sex-dimorphism-index, dominance of males, Križna jama, Slovenia

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Izvleček

Ne le podočniki (kanini), temveč skoraj vsi deli okostja, če so ohranjeni v večjem številu, so uporabni za ločevanje spolov. V Križni jami je opazna močna prevlada moških osebkov. Možnost razvrščanja v skupine (klastri), je odvisna od indeksov spolnega dimorfizma. Na podlagi primerjave podatkov iz različnih najdišč jamskega medveda,bomo razpravljali o možnih povezavah med spolnim dimorfizmom, razmerjem spolov, nadmorsko višino najdišča in taksonomsko pripadnostjo.
Ključne besede: razmerje spolov, indeks spolnega dimorfizma, prevlada samcev, Križna jama, Slovenija

1. Introduction

The sexing of cave bears faunas is based on the actualistic approach. It is assumed that – in analogy to the extant brown bear – the male cave bears were bigger than their female counterparts. This difference of sexes in respect of size is big enough, i.e. the biggest females are still smaller than the smallest males, so that there will form clusters when these data is used in a metric distribution, but only if there is sufficient material. The resulting clusters are interpreted as males and females. This theory is only true with the following two restrictions:

1. As it is based on the actualistic assumption, which can be found in the extant brown bear, it is only true for populations and not for the whole species because, for instance, female Grizzly bears (*Ursus arctos horribilis*) are bigger than males of the European brown bear (*Ursus arctos arctos*). When dealing with a fossil assemblage it must be reassured that the fossil remains belong to only one species and a defined evolutionary level.
2. This hypothesis is not true for all skeletal remains to the same extent. It was Kurtén (1955) who found out that it is nearly impossible to sex a population of bears based on molars, whereas the best results (separation of two clusters) are obtained with canines. Kurtén assumed

that the canines of cave bears were used as (show-)weapons during the rutting season.

In the following it will be investigated which skeletal elements allow for sexing and thus for an estimation of sex ratio and whether there is a difference of sexual dimorphism in teeth and bone. For this analysis only those skeletal elements with a number above 20 will be used. Two indices will be calculated to resolve this question:

Firstly, the sex-index (Rabeder, 2001) will be used instead of the sex-ratio to avoid undefined results like, for instance, if there were only females it would lead to a sex-ratio equalling ∞. Secondly, the sex dimorphism index (Baryshnikov et al., 2003) will be used as an indicator for the divergence of sex-specific means.

Sex-index: Amount of females in percent of the total amount of a specific skeletal element.

Sex dimorphism-index: Mean of the male cluster divided by the mean of the female cluster times 100.

In mathematical expressions, with f – number of females, m – number of males, x_f – mean of female values and x_m – mean of male values, it reads like:

$$\text{Sex-index} = \frac{f \times 100}{f + m}$$

$$\text{Sex-ratio} = \frac{f}{m}$$

$$\text{Sex dimorphism-index} = \frac{x_m \times 100}{x_f}$$

2. Material

Most of the material dealt with herein originates from the excavation campaign carried out in 2001. The smaller part, but the majority of the metapodial bones, is from the excavations carried out in 1878 and 1879 under the direction of Ferdinand von Hochstetter, see Hochstetter (1881).

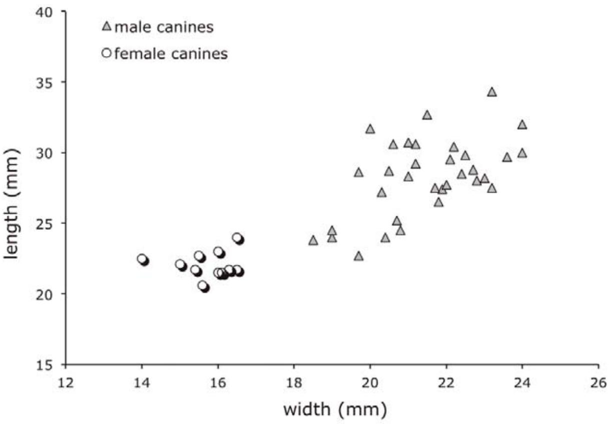

Figure 1: Scatter-plot of the canines from Križna jama (Slovenia).

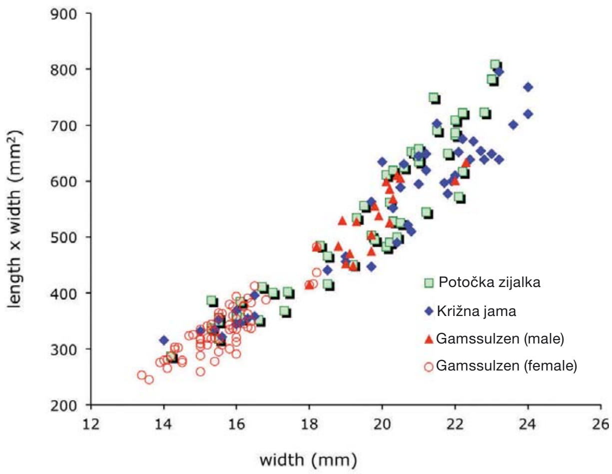

Figure 2: Sexing of cave bear canines from three different sites bearing remains from *Ursus ingressus*.

3. Sexing Based on Teeth and Metapodial Bones

3.1. Canines (Canini inferiores et superiores)

With the canines from Križna jama, a simple scatter-plot of crown width versus crown length results in two clearly separated clusters (see Fig. 1), which very likely represent the ratio of sexes. It must be noted that the crown-width proved to be a better factor for separating sexes than the crown-length. There were only 11 female canines opposed to 34 male canines, which leads to a sex-index equalling 24.44 and a sex-ratio of 0.32. The cave bear association from Križna jama was – at least in Kittl's Bärenhöhle – dominated by males, only a quarter of measurable canines were supposed to be female. A comparison with the canines from Potočka zijalka (Slovenia, see Pacher

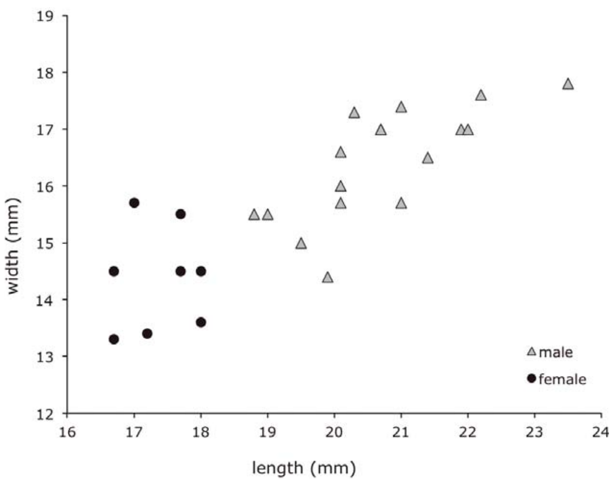

Figure 3: Sexing of the third upper incisors from Križna jama (Slovenia).

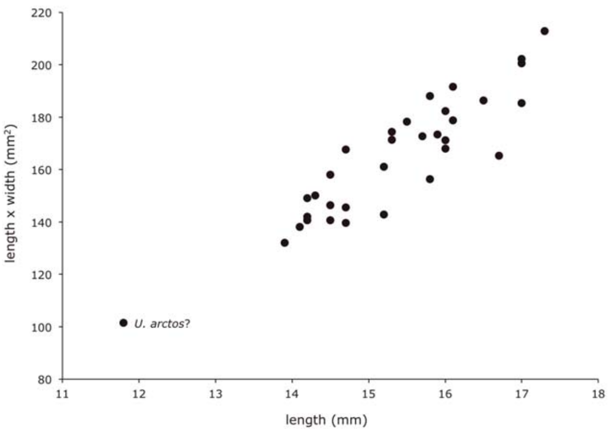

Figure 4: Scatter diagram of the lower fourth premolars from Križna jama.

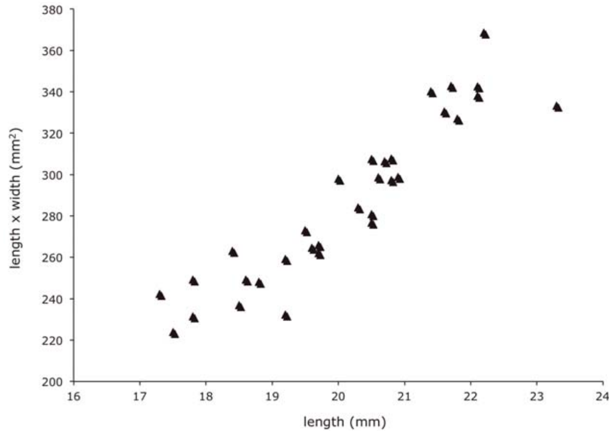

Figure 5: Scatter diagram of the upper fourth premolars from Križna jama.

et al., 2004) showed a convincing similarity between size distributions from these two cave bear sites, with only one difference: the separation of the clusters is more clear in Križna jama. A better separation can be achieved by applying the relation width to product length times width; unless this brings an improvement, some of the canines sexual attribution still remains enigmatic. Despite this fact, in Potočka zijalka there is a clear dominance of males too.

Opposed to the cave bear fauna from Gamssulzen cave (Upper Austria, see Rabeder, 1995), the reversed relation of sexes is striking: this fauna is clearly dominated by females. A comparison of the three aforementioned faunas enables us to do a better estimation of the real sex ratio in the Potočka fauna, see Tab. 1 and Fig. 2.

3.2. Third upper Incisor (I^3)

Despite the fact that there are only 25 third upper incisors in the material from Križna jama, a clear separation can be achieved when being put into a scatter-plot of length versus width. The sex-index equals 32.0 and the sex-ratio is 0.47 and is thus significantly higher than in canines. This result must not be overestimated, as the number of teeth is comparably low, see Fig. 3.

3.3. Premolars

Neither length nor width of the fourth premolars is suitable for a sexing. It is simply impossible to discover two clusters in the scatter-plots, which could represent the sex ratio. One of the fourth premolars is obviously out of the usual range because it is smaller, which could imply that it is from a brown bear, see Figs. 4+5.

3.4. Molars (Molares)

Based on common sense one would expect that molars are nor suitable for sexing. Nevertheless it was interesting for

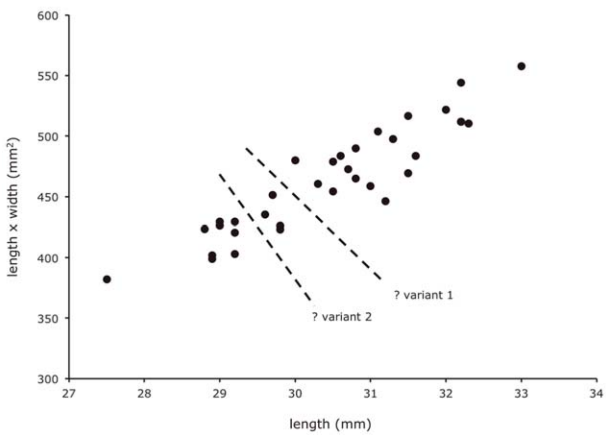

Figure 6: Scatter diagram of the lower first molars from Križna jama.

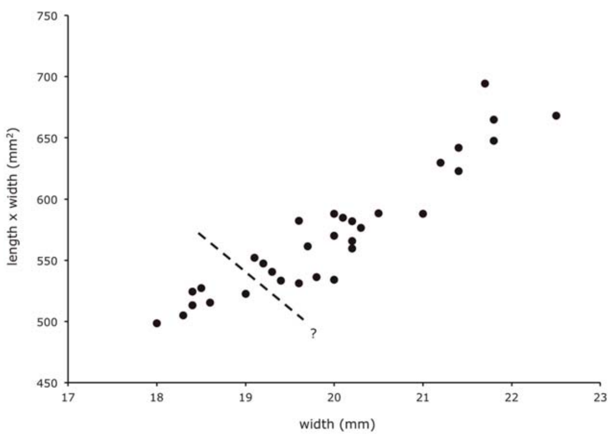

Figure 7: Scatter diagram of the upper first molars from Križna jama.

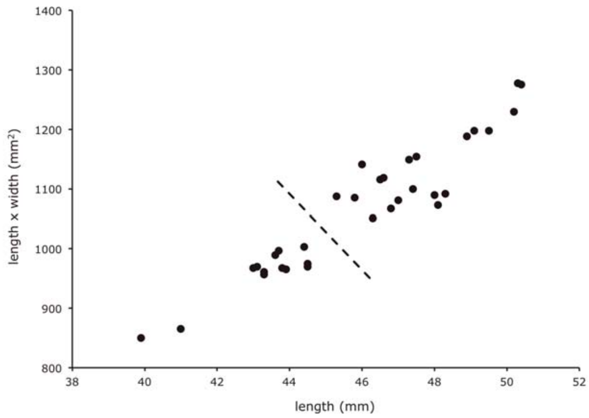

Figure 8: Sexing of the second upper molars from Križna jama for means of comparison with the distribution from the Gamssulzen M².

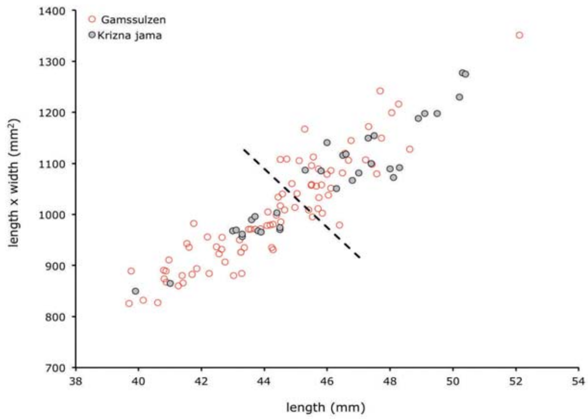

Figure 9: Sexing of the second upper molars from Križna jama superimposed on the distribution from Gamssulzen cave.

us to test whether the pattern of distribution (sex index of about 25 %), which was found in the canines, will also be reproducible with molars or not.

3.4.1. First Upper Molars (M¹)

The distribution area of the upper first molars splits into three groups; the group with the smallest values is supposed to be female whereas the two others are supposedly male. The calculated sex index is approximately 22 %, which comes quite close to the value calculated from canines, see Fig. 7.

3.4.2. First Lower Molars (M_1)

The lower first molars show the same pattern of distribution as their upper counterparts, i.e. a splitting into three groups. There is also a very small tooth too, which appears to be from a brown bear. In the diagrams below there are two possibilities for the separation of the females: the first variant, with 13 females and a sex index of 37.14 % is the more likely one, the second variant has only nine females and thus a sex index of 25.71 %. This is backed up by a comparison with the m1-distribution from Gamssulzen

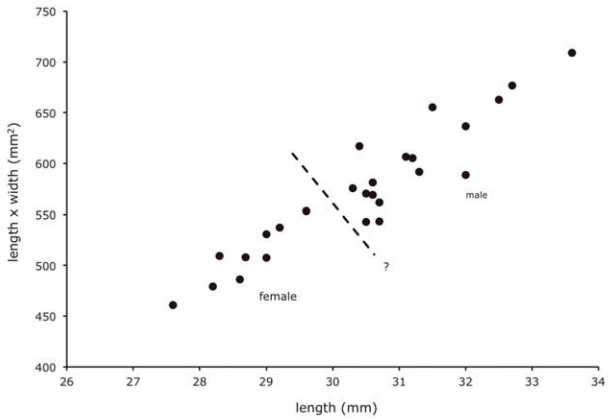

Figure 10: Sexing of the second lower molars from Križna jama.

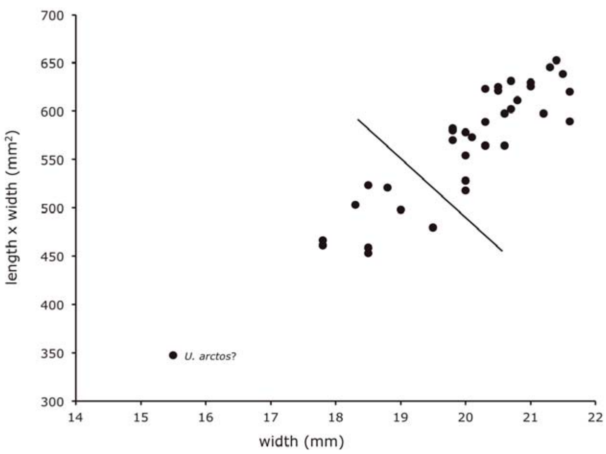

Figure 11: Sexing of the lower M_3 from Križna jama.

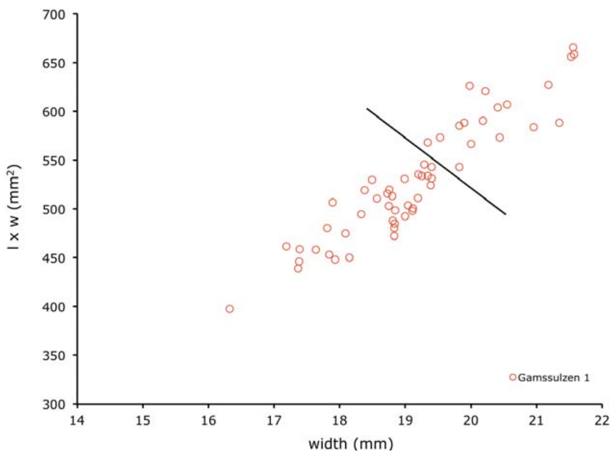

Figure 12: Sexing of the M_3 from Gamssulzen cave.

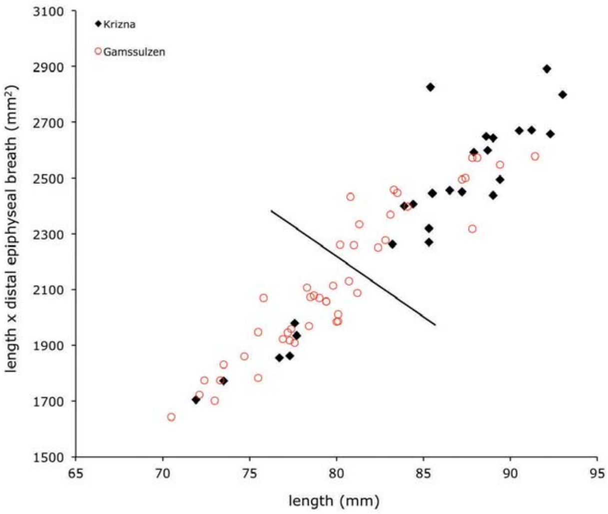

Figure 13: Sexing based on the third metacarpal bones from Križna jama in comparison with the material from Gamssulzen cave.

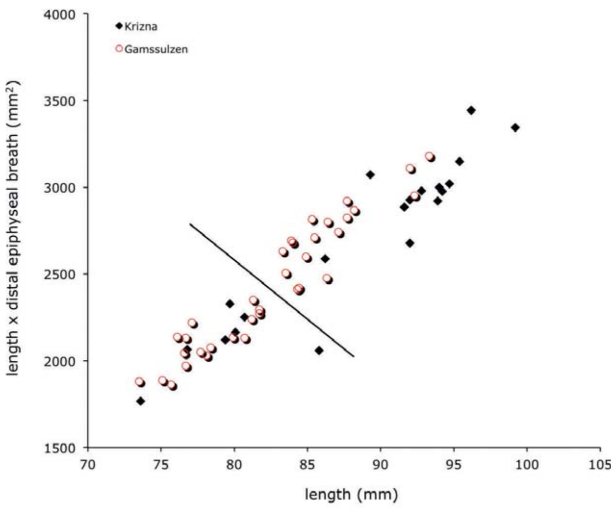

Figure 14: Sexing based on the fifth metacarpal bones from Križna jama in comparison with the material from Gamssulzen cave.

cave. Also the negative outlier, which has a length of only 27.5 mm, is within the distribution area of the m1 from Gamssulzen cave, see Fig. 6.

3.4.3. Second Upper Molars (M^2)

It was astonishing to see that the distribution area splits into two clearly separated groups, which seem to represent males and females. There are two significantly smaller teeth, which cannot be attributed to *Ursus arctos*, but – instead of this – belong to *U. ingressus* as shown by a comparison with the M^2-distribution from Gamssulzen cave. The sex index of the second upper molars from Križna jama equals 39 % and thus supersedes the value calculated from the canines by far. For better illustration see Figs. 8+9.

3.4.4. Second Lower Molars (M_2)

Also the second lower molars seem to offer the possibility of sexing. The two appearing clusters could probably refer to males and females. The resulting sex index of 32 % is lower than that from the second upper molars, but is still higher than that from the canines, see Fig. 10.

3.4.5. Third Lower Molars (M_3)

In a scatter-plot, the values obtained from the third lower molars are segregating into two clearly separated groups, which show a dominance of males. The resulting sex index equals 25 % and is thus congruent with the value from the canines. The distribution area of the third lower molars from Gamssulzen cave shows two clearly separated groups

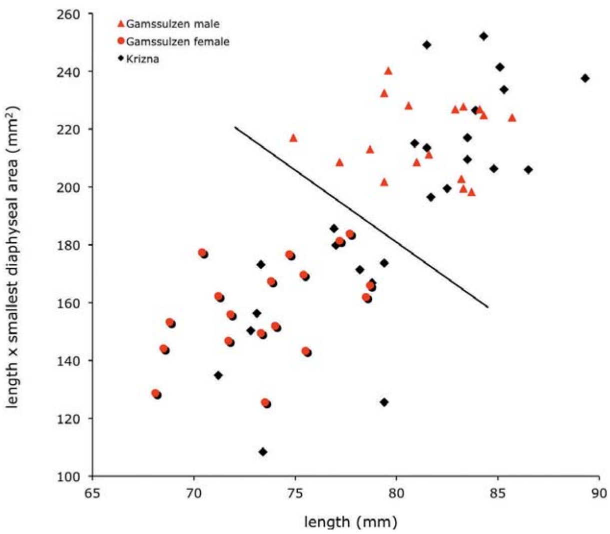

Figure 15: Sexing by means of the third metatarsal bones from Križna jama in comparison to those from Gamssulzen cave.

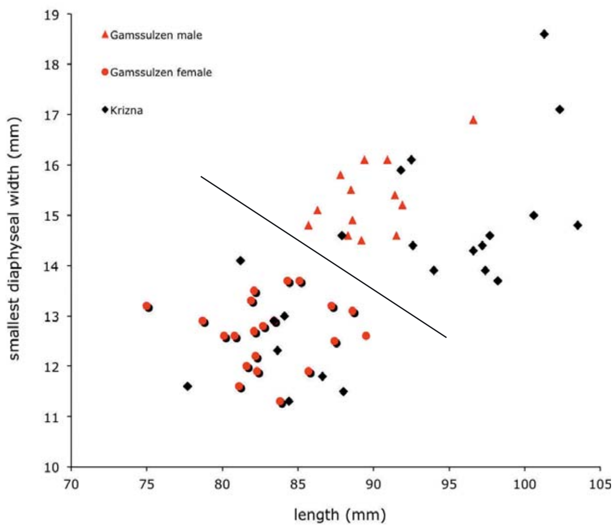

Figure 16: Sexing by means of the fifth metatarsal bones from Križna jama in comparison to those from Gamssulzen cave.

Križna jama	Female	Male	n	Sex index	Sex dimorphism index		Sexing is
Element					Length	Width	
canini	11	33	44	25.00	129.88	135.75	distinct
I^3	7	18	25	28.00	114.91	117.14	distinct
P^4	—	—	32	—	—	—	not possible
P_4	—	—	33	—	—	—	not possible
M^1	7	25	32	21.88	103.07	110.53	doubtful
M_1	13	22	35	37.14	106.84	106.70	doubtful
M^2	11	20	31	35.48	109.21	106.88	distinct
M_2	8	17	25	32.00	109.13	109.17	distinct
M_3	9	27	36	25.00	110.44	111.12	distinct
Mc3	6	21	27	22.22	115.86	118.52	distinct
Mc5	7	13	20	35.00	117.31	121.86	distinct
Mt3	9	15	24	37.50	111.58	117.46	distinct
Mt5	7	15	22	31.82	115.30	121.10	distinct

Table 1: Sex index and sex dimorphism index based on the analysis of teeth and metapodial bones from Križna jama.

with a dominance of the females (sex index = 75 %). In this distribution the length has greater influence than the width, see Figs. 11+12.

3.5. Metapodial Bones

In the material from Križna jama, there are only four metapodial elements which are sufficiently numerous to allow for a sexing: Mc3, Mc5, mt3 and mt5.

3.5.1. Metacarpals 3 and 5 (ossa metacarpalia III + V)

In a scatter diagram, the value pairs of the 3rd and 5th metacarpal bones are forming two clusters, which can be interpreted as males and females – based on a comparison with the material from Gamssulzen cave. The sex index calculated from the 3rd metacarpal bones equals 22.2 % and comes close to the value obtained from the canines (25 %), despite the comparably low number of specimens. On the other hand, the sex index of the 5th metacarpal bones is much higher, see Fig. 13+14.

3.5.2. Metatarsals 3 and 5 (ossa metatarsalia III + V)

The third metatarsal bones are clearly separating and form thus two distinct groups. During a proof with the material from Gamssulzen cave it showed up that a clear separation was only possible with a scatter plot of length versus volume; i.e. length x diaphyseal area. The resulting sex index

Gamssulzen	Female	Male	n	Sex index	Sex dimorphism index		Sexing is
Element					Length	Width	
canini	61	22	83	73.49	127.81	125.13	distinct
I^3	35	15	50	70.00	112.74	126.57	distinct
P^4	—	—	124	—	—		not possible
P_4	61	23	84	72.62	112.05	115.75	distinct
M^1	63	30	93	67.74	108.34	107.57	doubtful
M_1	—	—	76	—	no grouping		not possible
M^2	—	—	87	—	—		not possible
M_2	—	—	151	—	—		not possible
M_3	42	14	56	75.00	111.82	121.83	distinct
Mc3	28	17	45	62.22	108.28	113.49	doubtful
Mc5	20	20	40	50.00	111.25	117.58	distinct
Mt3	18	17	35	51.43	110.69	115.19	distinct
Mt5	21	12	33	63.64	107.71	113.80	distinct

Table 2: Sex index and sex dimorphism index based on the analysis of teeth and metapodial bones from Gamssulzen cave.

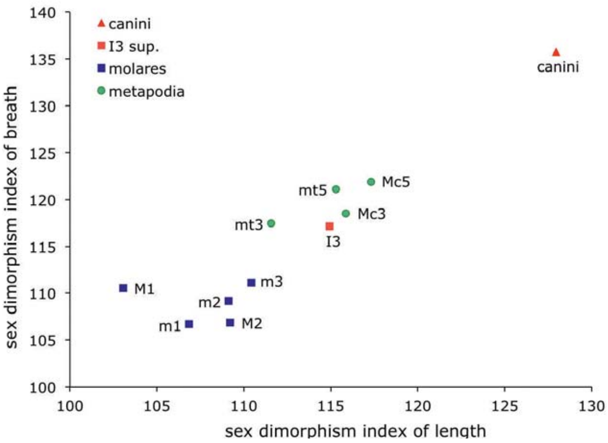

Figure 17: Sex dimorphism index of frequent skeletal elements (n > 20) from Križna jama.

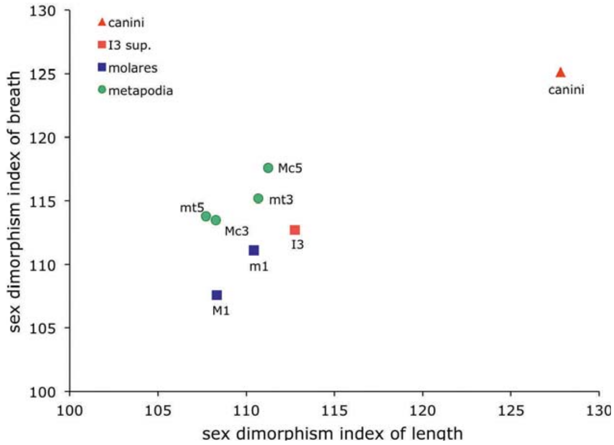

Figure 18: Sex dimorphism index of frequent skeletal elements (n > 20) from Gamssulzen cave.

equals 42.86 % and is thus by far higher than in any other skeletal element. Sexing by means of the fifth metatarsal bones is even easier than with the third metatarsals as they separate when being put into a scatter diagram of length versus diaphyseal width. From this results a sex index of 31.8 %, which comes closer to the value obtained from canines than that of the third metatarsals. The numerous big sized and slender metapodial bones from Križna jama are eye-catching, see Figs. 15+16.

4. Sex Index

4.1 Comparison of the Various Skeletal Elements

From the analysis of those skeletal elements with a number of n > 20 it can be deduced that a sexing is not equally reliable but strongly depends on the skeletal element in use. As the distributions show more or less clear separations for canines, incisors and even for metapodial bones, which can be interpreted as males and females, it

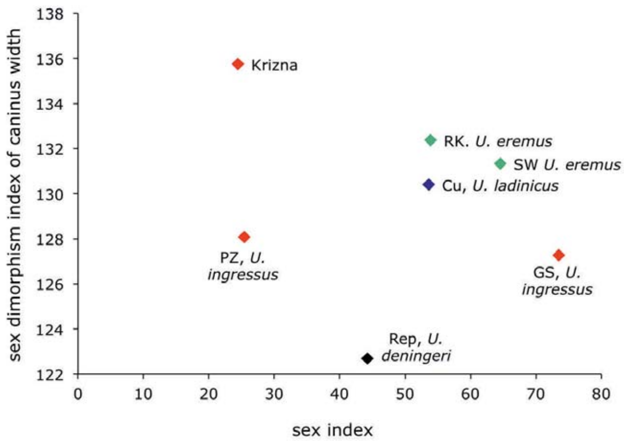

Figure 19: Sex-dimorphism of canines from different cave bear faunas and species.

Cave	Canini		n	Sex-Index	Alti-tude	Means: female		Means: male		Sex dimor-phism index		Species
	Female	Male				Length	Width	Length	Width	Length	Width	
Brieglersberg	22	7	29	75.86	1960	19.9	14.9	25.2	20.3	126.79	136.26	*ladinicus*
Conturines	52	45	97	53.61	2800	19.9	14.8	24.4	19.3	122.27	130.40	*ladinicus*
Gamssulzen	61	22	83	73.49	130	20.4	15.4	25.2	19.6	123.53	127.27	*ingressus*
Križna jama	11	34	45	24.44	670	22.1	15.7	28.7	21.3	129.88	135.75	*ingressus*
Potočka zijalka	16	47	63	25.40	1650	16.0	22.4	20.9	28.7	130.75	128.08	*ingressus*
Ramesch	82	72	154	53.25	1960	20.5	13.9	26.2	18.4	125.86	129.23	*eremus*
Schwabenreith	51	28	79	64.56	960	21.0	15.0	27.9	19.7	132.86	131.33	*eremus*
Repolust	23	29	52	44.23	525	18.5	14.1	23.3	17.3	125.95	122.70	*deningeri*

Table 3: Sex index and sex dimorphism index of canines along with the altitude of the sites.

is much more difficult or even impossible with molars. The assumption that this is correlated with sexual dimorphism is demonstrated in Figures 17 and 18. The sex related differences in size are expressed by means of the sex dimorphism index (sdi), refer to chapter 1. Introduction. The comparison with the indices obtained from the Gamssulzen material shows on one hand that there are striking differences in the possibility for sexing between the different bear faunas, and, on the other hand that there are also astonishing congruencies. This can be illustrated by the sexing of the third upper incisors and the third lower molars, which show identical sex indices.
Opposed to this, the results obtained from other teeth show strongly diverging distributions: either sexing is reliable, as in the second upper and lower molars from Križna jama and in the P_4 from Gamssulzen cave, or it is dubious as, for instance, in the first upper molars from both sites, or it is simply impossible as this is the case for the P^4 and M^2 and the M_1 and M_2 from Gamssulzen fauna and the upper and lower P4 from Križna jama.
On the other hand, sexing based on metapodial bones seems to be possible in most of the cases, but the sex index shows deviations from up to 25 % from the value obtained from canines. **Due to this fact, it should be avoided to calculate the sex ratio based on metapodial bones only!**

5. Sex Dimorphism Index

The sex dimorphism index can be calculated from every skeletal element that allows for sexing and thus for a calculation of the sex index. From Table 1 and 2 as well as from Figure 17 it is evident, that various skeletal elements show various results.
As already known and thus supposed, the canines show the by far biggest sex-related differences in size. The metapodial bones and the third upper incisors form a group of intermediate usability, whereas the molars have the smallest differences in size. This is at least true for the faunal remains from Križna jama and Gamssulzen cave, see Table 3.

Comparison with Alpine Cave Bear Faunas

In comparison with other alpine cave bear faunas it shows up that the sex dimorphism index of canines is neither correlated with the taxonomic attribution nor with the altitude of the bear site, but it is correlated with the sex index. The bears from Križna jama have unusual big sized canines, a feature which makes them unique amongst other bear faunas. This is especially true for the width of the canines when measured at the base of the crown, showing a mean that is more than 35 % above the mean of the female canines.

6. Conclusions

• The cave bear fauna from Križna jama is dominated by males: only a quarter of the thanatocoenosis was female. The domination of males is also visible in the distribution from other skeletal elements, even if the sex-index values strongly vary.

• Sexing based solely on metapodial bones or molars could easily produce wrong results.

• Sex dimorphism index shows the best results with canines and the worst with molars; metapodial bones and incisors are in between.

• The possibility of correct sexing increases with sex dimorphism index and is thus best with canines and worst with molars.

• Sex index and sex dimorphism index show no obvious correlation.

• It is very likely that the sex dimorphism index is neither correlated with the altitude of the site nor with the taxonomic attribution of the bears.

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Analysis of the Cave Bear Metapodial Bones from Križna jama (Slovenia)

by

Gerhard Withalm [1)]

Withalm, G., 2014. Analysis of the Cave Bear Metapodial Bones from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:117 – 122, Wien.

Zusammenfassung

Dieser Artikel beschreibt die Metapodien aus der Križna jama in Slowenien, die Teils am Institut für Paläontologie der Universität Wien und Teils am Naturhistorischen Museum Wien liegen. Es handelt sich dabei um sehr große und plumpe Metapodien, die lediglich von denen aus der Ajdovska jama, ebenfalls in Slowenien gelegen, noch übertroffen werden. Die artliche Zuordnung erfolgt zu *Ursus ingressus* Rabeder et al., 2004, wobei es auffällt, dass diese Metapodien im Mittel nur noch von denen eines *Ursus ladinicus* Rabeder et al., 2004 an Größe überboten werden. Eine Erklärung dafür bieten die für diese Arten unterschiedlichen ausgeprägten Anpassungsmodi an Umweltbedingungen, siehe Rabeder et al. (2008).
Schlüsselwörter: Križna jama, Slowenien, *Ursus ingressus*, Metapodien, Pleistozän

Abstract

This article describes the metapodial bones from Križna jama in Slovenia, which are housed in the collections of the Institute of Palaeontology, University of Vienna, and at the Museum of Natural History, both Vienna. These metapodial bones are very big and plump and are superseded only by those from Ajdovska jama, which is also situated in Slovenia. The bears are attribuTable to the species *Ursus ingressus* Rabeder et al., 2004 and it is astonishing that they are only superseded in size by a population of *Ursus ladinicus* Rabeder et al., 2004. A suiTable explanation for this behaviour can be found in different modes of responses to environmental conditions.
Keywords: Križna jama, Slovenia, *Ursus ingressus*, metapodial bones, Pleistocene

Izvleček

V članku so opisani metapodiji iz Križne jame, ki so deloma shranjeni na Inštitutu za paleontologijo Univerze na Dunaju in deloma v Naravoslovnem muzeju (Naturhistorisches Museum) na Dunaju. Metapodiji so zelo veliki in čokati (masivni). Po velikosti jih presegajo samo tisti iz Ajdovske jame v Sloveniji. Pripadajo vrsti *Ursus ingressus* Rabeder et al., 2004, pri čemer vzbuja pozornost dejstvo, da jih v povprečju po velikosti prekašajo le še metapodiji vrste *Ursus ladinicus* Rabeder et al., 2004. Pojasnilo nudijo različno izražene prilagoditve teh vrst na okolje (Rabeder et al., 2008).
Ključne besede: Križna jama, Slovenija, Ursus ingressus, metapodiji, pleistocen

Dedication

This article is dedicated to my friend and colleague, M.A. Brigitte Kaulich, from Nürnberg (Germany) who died – much too early – in 2006.

1. Introduction

The Križna jama, its German name is Kreuzberg Höhle, is a well-known cave in Slovenia, which is famous for its impressing size, flowstone-figures and, since 1926, for its water-part, consisting of 22 lakes, separated by flowstone cascades. It is possible to visit parts of the cave in the course of a guided-tour. Nevertheless, it is also famous for the huge amount of cave bear remains, which was excavated in the second half of the 19th century by the Austrian scientist Ferdinand von Hochstetter, in collaboration with Josef Szombathy and Karl Deschmann. The fauna of Križna jama was first mentioned and roughly described by Liebe (1879), but it was upon Ferdinand von Hochstetter to publish the first conclusive work on this cave and its bears along with a set of detailed maps of the "old part" and its position underneath Križna

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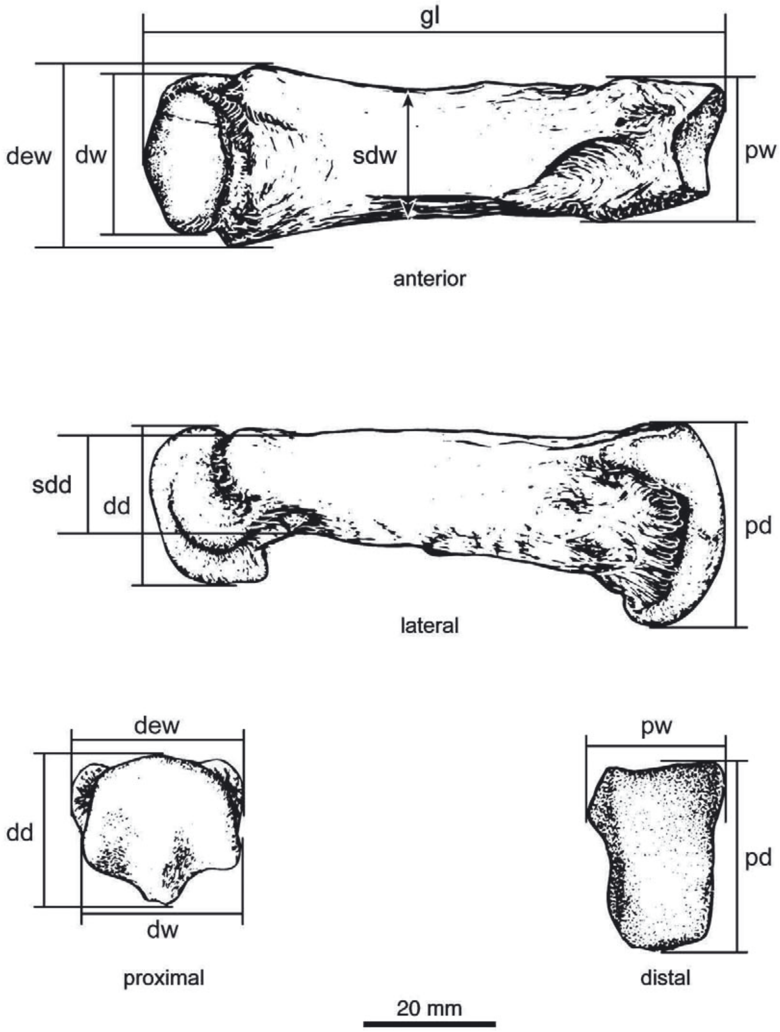
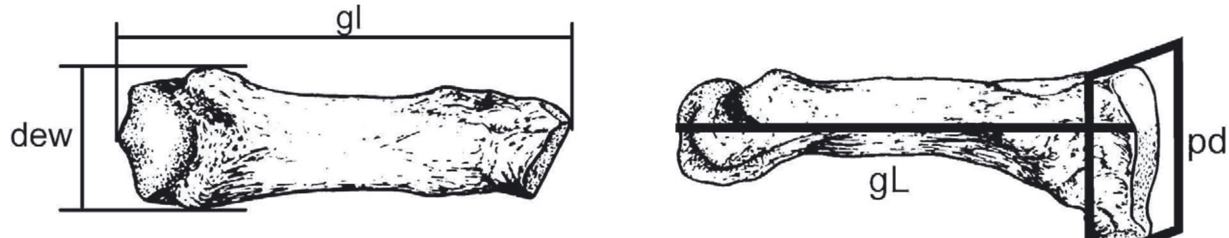


Figure 1: Measurements, taken on metapodial bones of members of the cave bear group, after Withalm (2001:177), illustrations after Torres Pérez-Hidalgo (1988), modified.



$$ip = \frac{dew}{gl} \times 100$$

$$K = \frac{(pw \times pd)}{gl}$$

Figure 2: The most important indices for cave bear metapodial bones. Left: index of plumpness, Withalm (2001:177), right: K-index, after Gužvića & Radanovič-Gužvića (2000), illustrations after Torres Pérez-Hidalgo (1988), modified.

gora, see Hochstetter (1881). Josef Szombathy made the survey of Križna jama and drew the maps in 1879 (Južnič, 2006). Another scientist whose name has a close connection to this cave is, as mentioned above, Karl Deschmann (Karel Dežman), the former curator of the Museum in Ljubljana (Slovenia) who gave his name for a part of this cave, Dežmanova vrata. In 1999 and 2001, two excavation campaigns were made under the supervision of Prof. Gernot Rabeder (Institute of Palaeontology, University of Vienna) and Prof. Vida Pohar (Ljubljana). The main task of these excavations was to recover more and fresh cave bear material from Križna jama, with the purpose to find more teeth for morphometrical analysis and also some fresh bones for

Element	n	gl	pw	sdw	dw	dew	pd	sdd	dd	da	pa	sda	ip	K
Mc1	18	68.6	26.6	13.7	20.3	20.4	21.0	10.4	19.7	404.4	560.5	143.7	29.73	8.13
Mc2	18	81.1	21.4	18.7	24.1	27.8	31.0	13.4	22.7	559.3	675.6	252.9	34.25	8.26
Mc3	28	85.3	23.0	18.0	23.8	27.9	31.8	13.7	23.6	565.1	752.7	249.4	32.81	8.67
Mc4	19	90.3	24.9	20.4	26.8	30.3	34.0	14.2	24.5	651.0	857.7	290.0	33.49	9.45
Mc5	23	88.3	32.3	19.3	29.2	30.2	36.6	14.0	23.3	710.1	1199.0	271.3	34.14	13.42
Σ Mc	**106**												**32.88**	**9.59**
Mt1	14	58.0	24.9	12.6	18.3	18.2	26.6	9.9	16.8	307.5	647.9	125.6	31.41	11.09
Mt2	24	72.0	16.5	19.4	20.1	23.0	25.9	10.7	18.0	329.7	430.0	160.4	32.05	6.17
Mt3	28	80.1	21.1	16.5	20.3	24.2	32.2	11.7	18.6	374.6	693.1	196.0	30.03	8.48
Mt4	19	92.4	22.8	17.6	23.3	26.6	32.6	13.6	21.1	500.2	740.4	240.3	28.75	8.01
Mt5	22	92.4	31.4	14.2	24.5	24.7	29.5	12.7	20.2	515.7	945.0	182.4	26.74	10.09
Σ Mt	**107**												**29.80**	**8.77**

Table 1: Metapodial bones from Križna jama (Slovenia). Measurements taken and indices calculated according to Withalm (2001:176–178). Abbreviations: gl – greatest length, pw – proximal width, sdw – smallest diaphyseal width, dw – distal width, dew – distal epicondyleal width, pd – proximal depth, sdd – smallest diaphyseal depth, dd – distal depth, da – distal area, pa – proximal area, sda – smallest diaphyseal area, ip – index of plumpness, K – K-index.

^{14}C-datations. Döppes (2001) analysed the *Gulo*-remains from Križna jama as a part of her PhD-thesis. Eva Wild made the datations at the VERA-Laboratory in Vienna (Austria). Actually, it was not only possible to make the datations, but it was also possible to carry out aDNA-analysis on the material. Michael Hofreiter from Max-Planck-Institute in Leipzig (Germany) carried out the latter analysis on mt-DNA, (Hofreiter, oral comm.).

2. Materials and Methods

The metapodial bones dealt with herein are part of the collections of the Institute of Palaeontology, University of Vienna, Austria (IPUW) and of the Museum of Natural History in Vienna (NHMW). The state of preservation of the specimens is good, so that it was possible to take nearly all measurements in most of the metapodial bones. After the excavations of the newly recovered material, the bones were carefully prepared at the Institute. The colour varies from ebony to cream. Table 1 gives an overview on the distribution of the material from Križna jama.
The methodology for acquiring measurements and for calculating the indices is the same as is published in Withalm (2001:176 – 178). Eight measurements were taken: greatest length (gl), proximal width (pw), smallest diaphyseal width (sdw), distal width (dw), distal epicondyleal width (dew), proximal depth (pd), smallest diaphyseal depth (sdd) and distal depth (dd). Four indices were calculated: proximal area (pa), smallest diaphyseal area (sda), distal area (da), index of plumpness (ip) and K-index (K), which are given in Table 1. See the measurements and indices in Fig. 1 and 2.

3. Results

It is obvious that a huge member of the cave bear group inhabited Križna jama approximately 45 ka b.p. The metapodial bones are big and plump, see Table 1 and Fig. 3 – 5. This is also true for the rest of the postcranial skeleton as well as for the impressively big skulls, excavated in 2001. Based on the analysis of ancient mt-DNA, the bears from Križna jama belonged to the species *Ursus ingressus*, a fact that wonderfully corresponds to what is actually known from the immigration route of this species until now.
In respect of the proportions of metacarpus and metatarsus, the bears from Križna jama are within the normal range of the cave bear group, without any significant differences.

4. Discussion

Even if it is obvious, the bears from Križna jama are big, even bigger than those from Potocka zijalka (Slovenia), compare to Withalm (2004), the upper levels in the Vindija cave (Croatia). In respect of the greatest length, only the bears from Ajdovska jama (Slovenia) supersede them, which are, despite their size, attributable to *U. ladinicus* Rabeder et al., 2004, see Rabeder, this volume. The different morphological responses of the single cave bear species especially in respect to their habitats altitude were published in Rabeder et al. (2008). In respect to the K-index only the bears from some upper Vindija-levels, compare to Withalm (2005), supersede the bears from Križna jama, see Fig. 6. Based on size and plumpness as well as on morphology the bears from Križna jama are clearly attribuTable to the species *Ursus ingressus*.

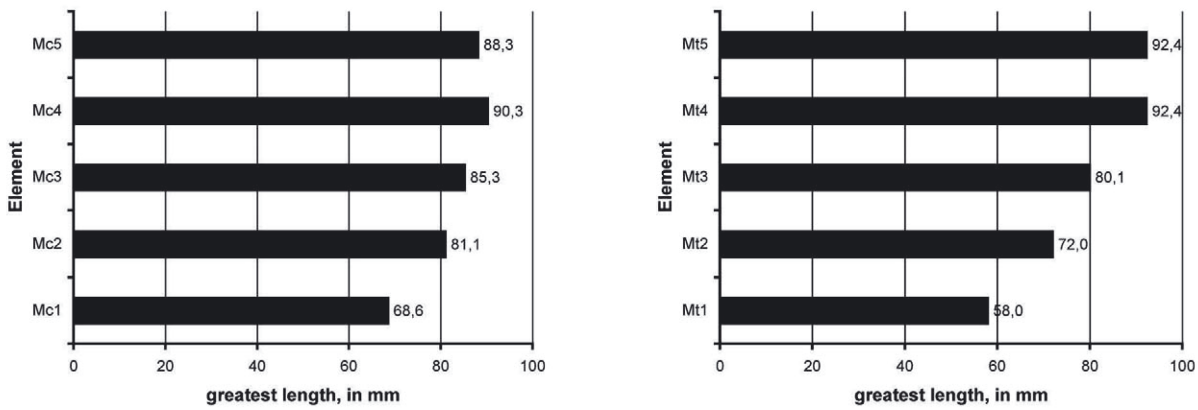


Figure 3: Proportions of metacarpus (left) and metatarsus (right) based on the greatest length.

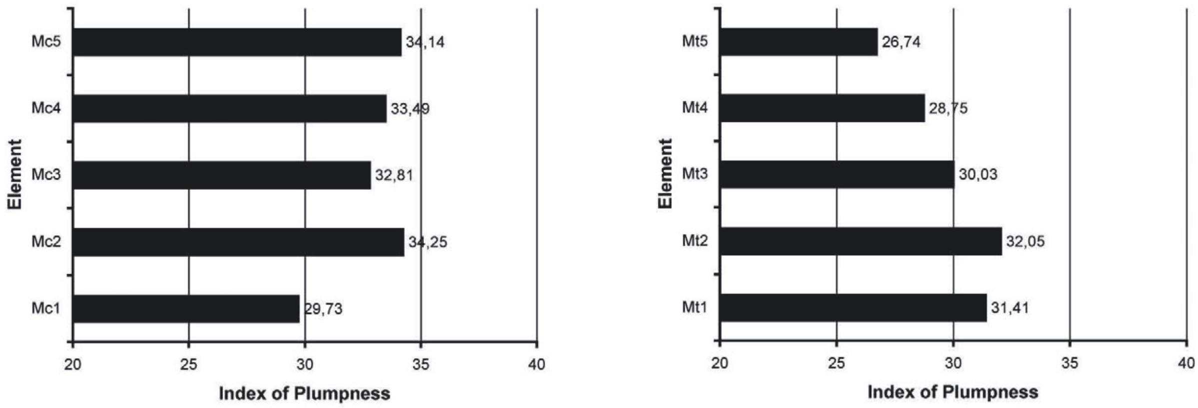


Figure 4: Proportions of metacarpus (left) and metatarsus (right) based on the index of plumpness.

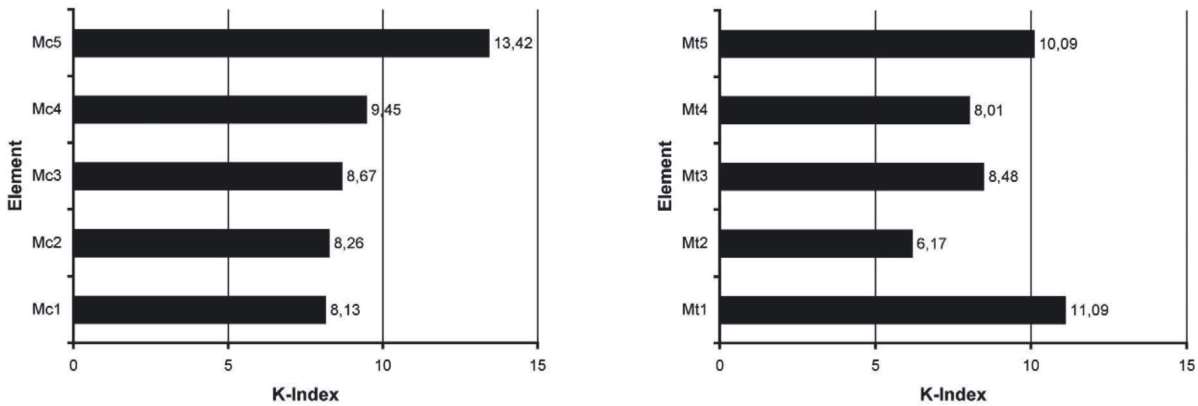


Figure 5: Proportions of metacarpus (left) and metatarsus (right) based on the K-index.

A fact that beautifully corresponds to the morphometrical analysis of teeth conducted by G. Rabeder as well as to the analysis of mt-DNA from M. Hofreiter. Moreover, it is interesting to observe the migration route of this species from east to west throughout time.

5. Acknowledgements

I am deeply indebted to Doz. Dr. Gudrun Höck from the Museum of Natural History in Vienna for allowing me to study the material stored in the collections of the museum and to o. Univ. Prof. Dr. Gernot Rabeder for his comments on this article.

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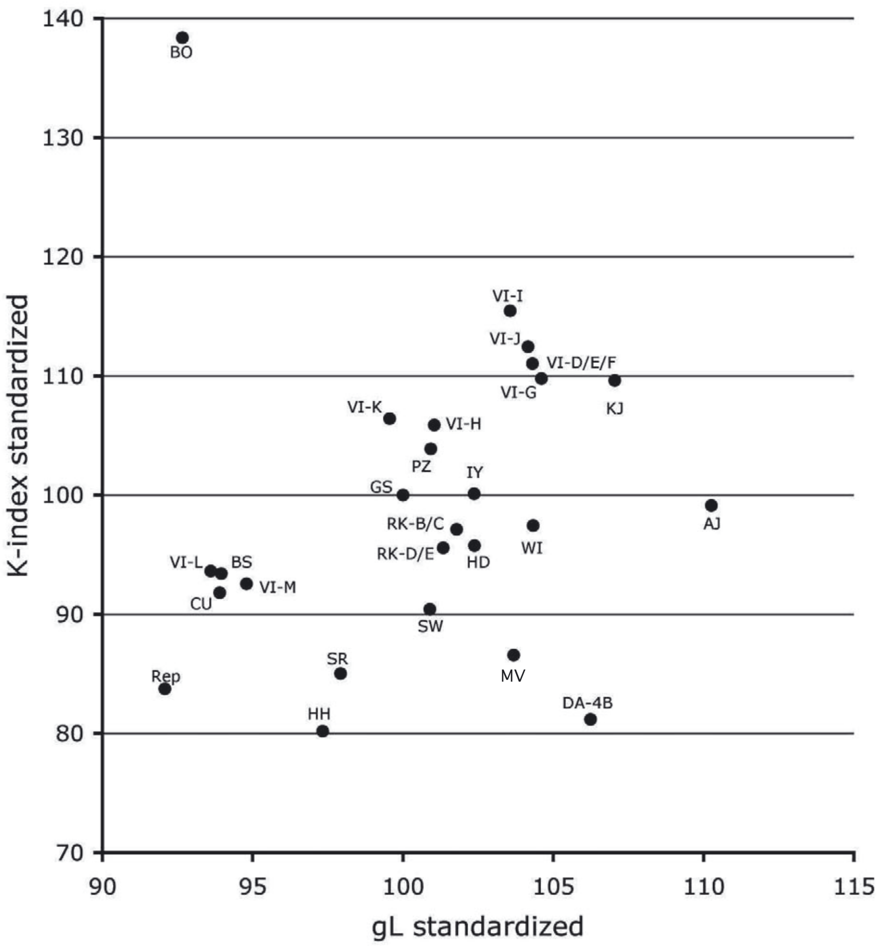

Figure 6: Scatter-plot of greatest length versus K-index of the second metatarsal bone from several studied sites, standardized on the *U. ingressus* from Gamssulzen cave in Upper Austria. Please note that the level of the K-index of the Križna-bears is one of the highest observed.

Abbreviations: AJ – Ajdovska jama (Slovenia), BO – Bucco dell'Orso (Italy), BS – Brettstein Bärenhöhle (Styria. Austria), CU – Conturines cave (South Tyrol, Italy), DA-4B – Bad Deutsch Altenburg, 4B (Lower Austria), GS – Gamssulzen-Höhle (Upper Austria), HD – Herdengel-Höhle (Lower Austria), HH – Hundsheim (Lower Austria), IY – Ilianka cave (Ukraine), KJ – Krizna jama (Slovenia), MV – Grotte de Merveilleuse (France), NB – Nerubajskoe (Ukraine), PZ – Potocka zijalka (Slovenia), Rep – Repolusthöhle (Styria, Austria), VI M-D/E/F – Vindija, layers M-D (Croatia), RK D/E – Ramesch Knochenhöhle, lower layers (Upper Austria), RK B/C – Ramesch Knochenhöhle, upper layers (Upper Austria), SR – Schreiberwandhöhle (Upper Austria), SW – Schwabenreith-Höhle (Lower Austria), WI – Windener Bärenhöhle (Burgenland, Austria).

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Additional Faunal Elements from Križna jama (Slovenia)

by

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Pacher, M. & Döppes, D., 2014. Additional Faunal Elements from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:123 – 129, Wien.

Abstract

This study is concerned with the carnivore remains from the cave site Križna jama in Slovenia. The number of faunal elements is relatively small. All bones and teeth came from old excavations. A short description of the fossil remains of wolf, wolverine and pine marten will be given.
Keywords: carnivores, Late Pleistocene, Križna jama, Slovenia

Zusammenfassung

Die Raubtierfunde aus der Höhle Križna jama in Slowenien werden vorgestellt. Die Individuenanzahl ist klein. Alle Knochen und Zähne stammen aus alten Grabungen. Die fossilen Funde von Wolf, Vielfraß und Baummarder werden kurz beschrieben.
Schlüsselwörter: Raubtiere, Oberpleistozän, Križna jama, Slowenien

Izvleček

V tej študiji so obravnavani ostanki karnivorov iz nahajališča Križna jama v Sloveniji. Število živalskih elementov je sorazmerno majhno, vsi ostanki kosti in zob pa izhajajo iz prejšnjih izkopavanj. Podajamo kratek opis ostankov volka, ameriškega rosomaha in kune zlatice.
Ključne besede: karnivori, zgornji pleistocen, Križna jama, Slovenija

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1. Introduction

The cave is located on the east side of the intermittent Lake Cerknica at Lož, about 20 km E of Postojna. The eight km long Križna jama is well known for its rich stalagmite decoration and its underground lakes as well as for the numerous cave bear remains. The water part was discovered in 1926. First excavations took place in 1878 and 1879 by F. von Hochstetter (1881). Cave bear bones could be detected only in two areas of the cave (Medvedji rov/Bear Passage and Kittlova brezna/Kittl's Abyss). However, evidence of additional faunal elements is rare.
The fauna according to Hochstetter (1881:305) consists of *Ursus spelaeus* (99%, all ages, 2000 bones, more than 100 individuals), *Canis lupus*, *Martes foina* and *Gulo gulo*.

2. Methods

A short description of the fossil remains from Križna jama will be given. Bones and teeth were measured to the nearest 0.1 mm following the definitions of van den Driesch (1976). The number of individuals (MNI) and bone elements (brackets) is given for each species.

3. Description of the Material

Among additional faunal elements five species are confirmed. All of them were found during the old excavations. Liebe (1879) already mentioned an epistropheus and a third cervical vertebra of *Canis lupus*. The two vertebrae are grown together. In addition, an ulna from *Gulo gulo* and a skull from *Martes martes* (pine marten) were mentioned. Already Liebe (1879) stated that the skull looks modern suggesting diluvial age. Hochstetter (1881) gives evidence of the origin of these finds. They all were found at the terrace called "Bärenwirtshaus" in the Medvedji rov / Bear Passage approx. 400 meters from the cave entrance. In addition to the above specimens he also mentions a left mandible from *Gulo gulo*, a mandible

	Tl	bp	bd	SD
KJ	52.8	20.0	16.3	12.3
Arrikrutz	57	24	20.5	16.5
Extant male	44 – 49 (n = 7)	—	—	—
Extant female	41 – 43.5 (n = 3)	—	—	—

Table 1: *Panthera spelaea*; measurements (in mm) of phalanx 1 anterior, digit V from Križna jama (KJ) compared with Arrikrutz (Altuna, 1981) and extant lions (Gross, 1992:46). **Abbreviations**: Tl – total length, bp – proximal width, bd – distal width, SD – smallest diaphyseal width

and a right humerus from a marten (*Mustela foina* ?). This material is still housed at the Natural History Museum (NHMW) in Vienna.

Hochstetter (1881:305) denied explicitly any finds of the cave hyena and the cave lion, but one phalanx of *Panthera spelaea* is housed at the Institute of Paleontology (IPUW) in Vienna, which comes from a small assemblage probably collected by Janesch in 1902 (Table 1). This material contains also a pelvic bone from goat and one m2 from dog.

An additional fragment of a humerus from *Canis lupus* is housed at the depot (BTC-Lj) in Ljubljana. This find comes from the excavation by Brodar and Gospodarič in 1971.

Canis lupus Linnaeus, 1758 – Wolf

Material: 1 tibia dex (NHMW 1879), 1 humerus fragment distal (BTC-Lj), 1 metacarpal V (NHMW), 1 metatarsal II (NHMW), 2 cervical vertebrae (NHMW), MNI 2 (6)

The dimension of the right tibia can be compared with those of the extant wolves (Table 2). The tibia and the metapodials do not belong to the same individual. The tibia from Križna jama is small but rather broad at the proximal end and hence similar to specimens from Drachenhöhle and Salzofenhöhle. It cannot be excluded that these unstratified specimens belong to domestic dogs (Table 2) but a more detailed analysis is needed. Gnawing marks cannot be determined on the bones. The mcV and the mtII are from a very large individual, even larger than other Upper Pleistocene remains from Austria and Slovenia (Table 3). At the humerus fragment pathological bone growth can be observed (Fig. 1).

Martes martes (Linnaeus, 1758) – Pine marten

Material: 1 cranium (NHMW A5358), 1 mandible sin. (NHMW A5358), 1 humerus dex. (NHMW A5358), MNI 2 (3)

The almost complete skull (Table 4) is only broken at the right zygomatic arch. The preserved P2, P4 and M1

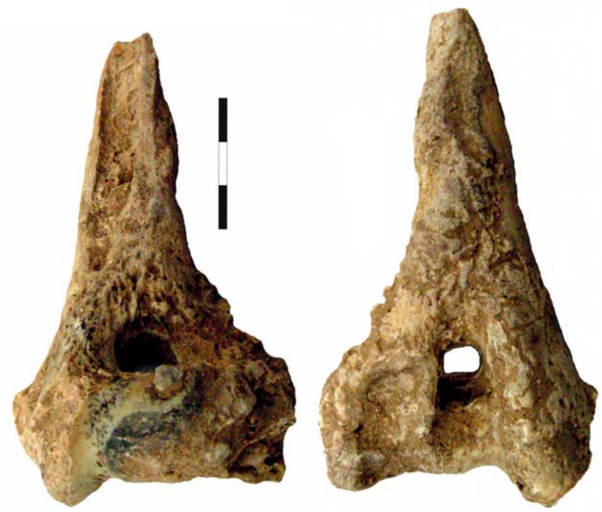

Figure 1: *Canis lupus*, distal humerus fragment with pathological bone growth, anterior and posterior view (BTC-Lj, Photo: M. Pacher).

Sites	Tl (n)	bp (n)	bd	SD (n)	SDD (n)
KJ	198.30	39.80	26.20	19.70	20.80
Drachenhöhle	206	43.0	18.0	—	—
Salzofenhöhle (Vb)	216.15	38.27	24.48	—	—
Extant male	243.8 ±21.9 (11)	46.6 ±2.1 (5)	—	16.9 ±1.5 (5)	17.6 ±1.8 (5)
Extant female	235.8 ±19.5 (8)	45.8 ±1.6 (4)	—	16.1 ±1.5 (4)	18.2 ±0.9 (4)

Table 2: *Canis lupus*; measurements (in mm) of tibiae from Križna jama (KJ), Drachenhöhle near Mixnitz (Austria, Sickenberg, 1931: 751), Salzofenhöhle (Austria, Pacher & Döppes, 1997: 137) and extant species (Doyle, 2009:70). **Abbreviations**: Tl – total length, (n) – number, bp – proximal width, bd – distal width, SD – smallest diaphyseal width, SDD – smallest diaphyseal depth

(Table 5) show the typical characteristics of the pine marten, *Martes martes* (e.g. the transverse M1 has a rounded buccal edge, Wolsan et al., 1985).
The complete left mandible with p2–m1 (Table 6) belongs to the pine marten *Martes martes*. The relatively large distance (7.3 mm) between the foramina mentalia is longer in *M. martes* than in *M. foina* (Stubbe, 1993: 372; Anderson, 1970).
The right humerus fragment is nearer in size to *Martes martes* than to *M. foina* (see Table 7). The small size of our comparative material prevents a clear assignment of the humerus to *Martes* sp.

Gulo gulo (Linnaeus, 1758) – Wolverine

Material: 1 mandible sin. (NHMW 1878), 1 ulna sin. (NHMW 1878), MNI 2 (2)

The mandible is broken under the anterior root of the first molar (m1) and was glued together. Only the uppermost part of the horizontal branch is broken off. The alveoli of p1, p4 and m2 are only very well visible in X-rays (Fig. 2). The teeth (C, p2, p3 and m1, Table 8) are worn down significantly. The mandibular foraminae are the same size. The mandible was examined radiographically in order to

	mc V						mt II			
Sites	**Tl**	**bp**	**dp**	**bd**	**bda**	**SD**	**L**	**pb**	**db**	**SD**
KJ	82.50	17.40		15.60	14.0		92.40		10.20	7.9
Potočka zijalka		14.40	14.0					6.70	15.30	8.5
Mokriška jama	76.20		14.4	12.80						
Drachenhöhle	73.11			13.61			89.26		14.90	
Salzofenhöhle (Vb)							73.57		9.29	
Griffen							88.80		12.30	
Veternica	81.3–84.6						82.2–98.6		9.29	
Extant male	64.20	14.80	12.4	11.30		8.5	73.4	8.50	10.6	6.8
Extant female	64.10	14.50	11.5	11.50		7.2	74.1	8.15	10.0	6.0
							74.2	7.90	10.4	6.0
							79.5	8.20	10.3	6.0
							80.4	7.90	10.7	6.2

Table 3: *Canis lupus*; measurements (in mm) of mc V and mt II from Križna jama (KJ), different Late Pleistocene sites (Döppes, 2004:74; Pacher & Döppes, 1997:139; Thenius, 1960:36; Malez, 1963:62 (n=?)) and extant species (Döppes, 2004:74). **Abbreviations**: Tl – total length, bp – proximal width, dp – proximal depth, bd – distal width, bda –width of distal articulation, SD – smallest diaphyseal width

Skull	**Sex**	**Cbl (n)**	**Mast (n)**	**Ect (n)**	**Pob (n)**
KJ		85.4	38.5	26.2	18.0
***M. martes*, Austria**	m	81.08–88.64 (29)	—	24.09–29.39 (31)	17.01–22.15 (30)
	f	77.6–79.78 (4)	36.03–37.97 (4)	22.30–25.73 (4)	17.63–18.63 (4)
***M. martes*, Europe**	m	79.8–88.4 (18)	—	—	—
	f	73.6–80.1 (11)	—	—	—
***M. foina*, Austria**	m	77.46–87.58 (32)	35.90–42.37 (28)	23.49–32.21 (30)	17.62–22.37 (30)
	f	76.98–82.28 (7)	37.09–39.72 (7)	25.40–29.87 (7)	17.62–20.52 (6)
***M. foina*, Europe**	m	78.3–85.1 (56)	36.0–42.3 (43)	—	15.7–22.0 (52)
	f	72.0–81.0 (61)	35.0–39.6 (41)	—	15.6–21.6 (57)

Table 4: *Martes foina* and *Martes martes*; measurements (in mm) of skulls from Križna jama (KJ) and extant species of Austria (Spitzenberger, 2001) and Europe (Anderson, 1970). **Abbreviations**: cbl – condylobasal length, ect – greatest frontal breadth, gmb – greatest mastoid breadth, pob – least breadth between the orbits, m – male, f – female, (n) – number

Teeth	Sex	L–P4 (n)	B–P4 (n)	L–M1 (n)	B–M1 (n)
KJ		8.4	5.2	6.3	8.2
M. martes, Austria	m	7.79 – 9.16 (25)	4.94 – 5.87(25)	5.25 – 6.63 (25)	7.85 – 8.88 (25)
	f	7.04 – 8.18 (31)	4.37 – 5.52 (31)	4.81 – 5.93 (31)	6.78 – 8.30 (31)
M. foina, Austria	m	8.26 – 10.00 (33)	4.76 – 6.09 (33)	4.81 – 6.86 (32)	8.04 – 9.36 (32)
	f	8.53 – 9.13 (7)	4.45 – 5.63 (7)	4.62 – 5.80 (7)	7.70 – 8.51 (7)
M. martes, Europe	m	7.8 – 9.3 (21)	—	—	7.8 – 8.9 (24)
	f	7.1 – 8.2 (13)	—	—	7.5 – 8.2 (16)
M. foina, Europe	m	8.4 – 10.0 (56)	—	—	7.9 – 9.5 (56)
	f	7.7 – 9.0 (50)	—	—	7.5 – 8.9 (49)

Table 5: *Martes martes* and *Martes foina*; measurements (in mm) of upper teeth from Križna jama (KJ) and extant species of Austria (Spitzenberger, 2001) and Central Europe (Anderson, 1970). **Abbreviations**: L – length, B-breadth, m – male, f – female, (n) – number

Mandible	Sex	Gl (n)	Mh (n)	L-m1 (n)	B-m1 (n)
KJ		58.1	26.0	11.4	4.2
PZ-926		53.3	24.5	9.4	—
M. martes, Austria	m	53.87 – 60.82 (30)	23.17 – 26.79 (30)	9.35 – 10.99 (31)	3.86 – 4.66 (31)
	f	51.29 – 53.95 (5)	21.93 – 23.45 (5)	9.29 – 9.76 (5)	3.91 – 4.30 (5)
M. martes, Europe	m	53.5 – 62.2 (32)	24.3 – 28.0 (29)	9.4 – 11 (34)	—
	f	47.9 – 59.2 (21)	20.5 – 25.3 (20)	8.4 – 10.5 (21)	—
M. foina, Austria	m	52.56 – 58.42 (32)	22.90 – 28.19 (33)	8.65 – 11.02 (33)	4.03 – 5.05 (33)
	f	51.02 – 55.5 (7)	22.97 – 25.52 (7)	8.48 – 9.93 (7)	3.88 – 4.55 (7)
M. foina, Europe	m	51.0 – 57.2 (43)	23.4 – 27.4 (59)	8.6 – 10.6 (62)	—
	f	48.0 – 53.6 (43)	20.6 – 24.9 (62)	7.8 – 9.8 (60)	—

Table 6: *Martes martes* and *Martes foina*; measurements (in mm) of mandibles from Križna jama (KJ), Potočka zijalka (PZ, Döppes, 2004) and extant species of Austria (Spitzenberger, 2001) and Europe (Anderson, 1970). **Abbreviations**: Gl – mandible length between Processus angularis and Infradentale, Mh – mandible height, L – length, B-breadth, m – male, f – female, (n) – number

Site	Sex	Tl (n)	bp (n)	dp	bd	bt	SD
KJ	—	—	10.8	11.7	—	—	4.3
M. martes, Veternica	—	70.4	—	12.9	15.1	10.4	—
M. foina, Central Europe	m	66.5 – 69.9 (14)	14.4 – 15.8 (14)	—	—	—	—
	f	60.0 – 65.4 (17)	12.9 – 14.3 (17)	—	—	—	—

Table 7: *Martes martes* and *Martes foina*; measurements (in mm) of humeri from Križna jama (KJ), Veternica (Croatia, Miracle & Braijković, 2010) and extant species of Central Europe (Stubbe, 1993). **Abbreviations**: Tl – total length, bp – proximal width, dp –proximal depth, (n) – number, bd – distal width, bt – breadth trochlea, SD – smallest diaphysis width, n – number, m – male, f – female

		L-C	B-C	L-p2	B-p2	L-p3	B-p3	L-p4	B-p4	L-m1	B-m1
KJ		10.20	9.50	6.40	4.20	7.70	5.60			22.10	9.20
Jvp		11.00	9.20	7.00	4.70	8.80	6.10	12.00	7.50		
Jvp		11.10	8.80					12.40	7.90	22.20	10.10
Knk						8.50	5.70	12.50	8.00	23.50	11.00
Lj		10.80	11.80	6.00	5.30	9.40	6.70	13.80	9.20	23.90	11.70
Norway female	n	15	15			15	15	15	15	15	15
	min	9.25				6.90	4.50	9.30	6.30	18.00	7.30
	max	10.35				8.30	5.50	11.30	7.90	20.40	8.50
	d					7.35	4.91	10.31	7.14	19.12	8.10
Norway male	n					14	14	14	14	13	13
	min					7.20	4.70	10.60	6.90	19.55	8.30
	max					8.70	5.40	11.60	8.50	21.70	9.50
	d					8.02	5.04	11.19	7.75	20.64	8.85

Table 8: *Gulo gulo*; measurements (in mm) of lower teeth from Križna jama (KJ), other Late Pleistocene remains in Slovenia (Pavšic & Turk, 1989) and extant species of Norway (Döppes, 2001). **Abbreviations**: KnK – Kostanjevica na krasu, Lj – Ludvikova jama, Jvp – Jama velikih pod kovnjakov, L – length, B – width, n – number, min – minimal, max – maximum, d – mean value

		T1	bd
KJ		137.00	11.60
male	n	21	21
male	min–max	133.89–152.80	11.50–14.90
male	m	144.23	13.20
female	n	20	19
female	min–max	124.7–137.1	10.20–13.00
female	m	128.88	11.72

Table 9: *Gulo gulo*; measurements (in mm) of ulnae from Križna jama (KJ) and extant specimens (Döppes, 2001). **Abbreviations**: T1 – total length, bd – distal width, n – number, m – mean value

investigate the bone behind the m1. In other European findings (Döppes, 2001, 2005) the clear absence of m2 by X-ray images could be demonstrated. Based on the compilation of extant remains and Late Pleistocene finds, however, no correlation with geographical, biological or chronological parameters is evident. In the sites Drachenhöhle near Mixnitz (Austria) and Villereversure (France) mandibles with and without the m2 even come from the same site.

The well preserved ulna was first mentioned by Liebe (1879). Its dimensions (Table 9) compared with the extant species are smaller than the dimensions of the mandible and therefore the ulna belongs to another individual.
Gulo gulo remains are known in Slovenia from the Potočka zijalka (1 maxilla-fragment and a canine tooth, Döppes, 2004), Ludvikova jama (1 right mandible without m2, 3 maxilla, 1 maxilla-fragment (Pavšic & Turk, 1989; Döppes, 2000), Jama velikih pod kovnjakov (2 mandible-fragments, 3 canines, 1 incisor, Döppes, 2001) and Kostanjevica na Krasu (an almost complete skeleton, Anelli, 1941).

4. Conclusion

The present analysis described the carnivores from the old excavation for the first time. Wolf, cave lion, and also wolverine are typical additional faunal elements known from numerous cave bear sites. The remains from pine marten consist probably of recent (skull) and fossil material.
Canis lupus represents a faunal element that tolerates a wide range of environmental changes. In Europe, the wolf was found in all habitats except in high-alpine areas. Today the occurrence is limited to wooded mountain ranges or contiguous forests, swamps and tundra (Peters, 1993). Wolves are carnivores, occasionally the consumption of fruits and waste can be observed.
Martes martes strongly depends on forest (Stubbe, 1993). It has a more northern distribution than *Martes foina* and

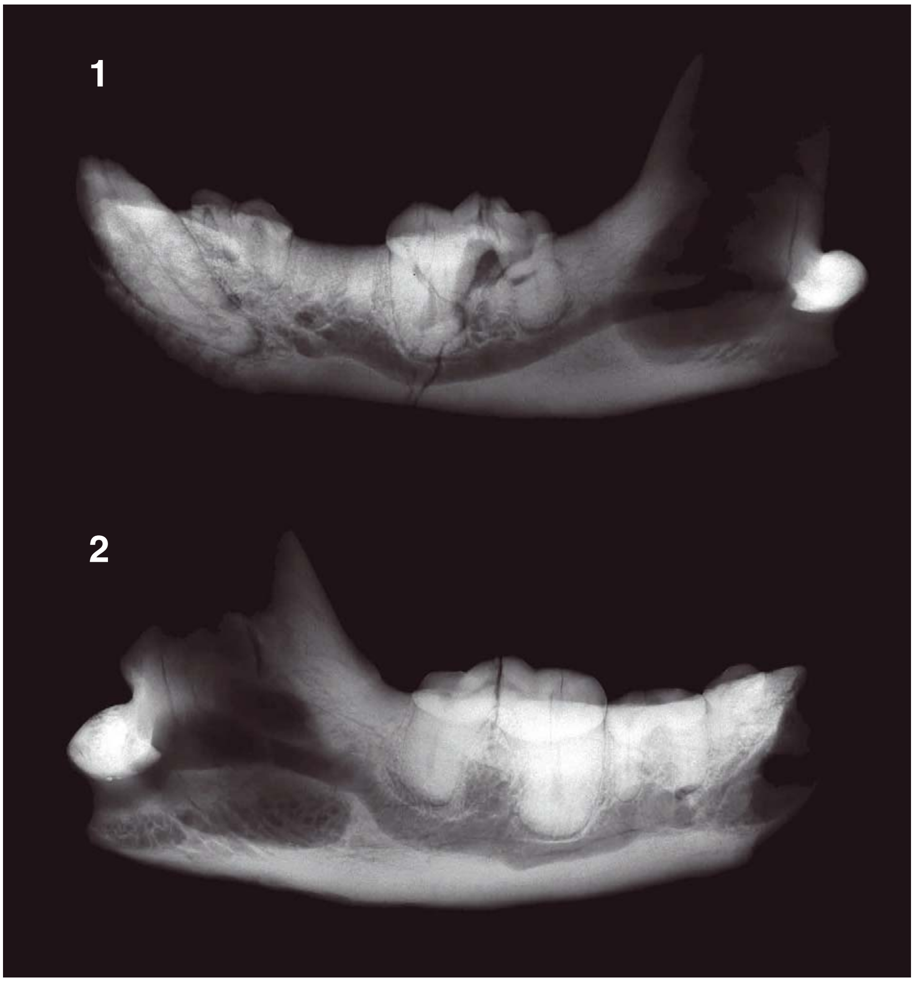

Figure 2: *Gulo gulo*; X-ray photograph of mandibles from Križna jama (1) and Drachenhöhle near Mixnitz (Austria, 2). Natural size. X-ray: Gerhard Withalm

is found from the Scandinavia, British Islands to Italy, from North-Spain eastward to Asia Minor. *Martes foina* has a similar distribution than *Martes martes*, but the pine marten avoids human neighbourhood. Since *Martes foina* was a late immigrant to Europe, probably from the Middle East, records of its presence in Würmian deposits should, as Kurtén (1968) noted, be viewed with suspicion. Even Anderson (1970) and Sato et al. (2003) described *Martes foina* as a present-day species. Both martens feed on small mammals, birds, fruits and berries.

The wolverine is the biggest European mustelid and a typical animal of the North. It inhabits coniferous forests and the taiga of Scandinavia and Finland where it visits different biotopes seasonally. In summer, wolverines prefer forests, and in winter they live in the tundra. Outside of Europe, one also finds them in northern Asia and North America. This big mustelide is an omnivore that feeds, in addition to fresh meat, on carrion and on berries in late summer.

5. Acknowledgements

Thanks for support to Prof. Dr. Gernot Rabeder and Prof. Dr. Vida Pohar and of course the whole excavation team from Slovenia and Austria. Dr. Ursula Göhlich from the Natural History Museum in Vienna provided access to the material housed at the Department of Geology and Palaeontology.

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Stratigraphy and Chronology of the Fossiliferous Layers from Križna jama (Slovenia)

by

Gernot Rabeder [1), Gerhard Withalm [2) & Eva Maria Wild [3)

Rabeder, G., Withalm, G. & Wild, E.M., 2014. Stratigraphy and Chronology of the Fossiliferous Layers from Križna jama (Slovenia). — Mitt. Komm. Quartärforsch. Österr. Akad. Wiss., **21**:131 – 136, Wien.

Zusammenfassung

Alle fossilen Faunenreste stammen aus Schichten, die durch fluviatile Umlagerungen geprägt sind, sie liegen also auf sekundärer Lagerstätte. Die Bärenreste der Križna jama haben radiometrische Alter zwischen rund 47.000 und 32.000 Jahren vor heute. Ein datierter Holzkohlerest zeigt an, dass Umlagerungen bis in die jüngste Zeit erfolgt sind.
Schlüsselwörter: Allochthone Sedimente, Križna jama, ^{14}C-Daten

Abstract

All fossil remains originate from layers, which are dominated by fluviatile rearranging of the sediments, i.e. they are allochthonous. The cave bear remains from Križna jama are dated by means of ^{14}C-dating to ages between 47 and 32 ka BP. There were also charcoal remains found and dated, showing that fluviatile transport of sediments took also place in historic times.
Keywords: allochthonous sediments, Križna jama, ^{14}C-datings

Izvleček

Vsi fosilni živalski ostanki izhajajo iz vodno preloženih plasti in se nahajajo na drugotnem mestu. Radiometrična starost medvedjih ostankov iz Križne jame se giblje med 47.000 in 32.000 leti našega štetja. Datiran kos lesa dokazuje, da se je prelaganje plasti vršilo do novejšega časa.
Ključne besede: alohtoni sedimenti, Križna jama, ^{14}C

1. Description

It was Ferdinand von Hochstetter (1881:15) who realized that all the fossil bearing loams in Križna jama are situated in higher parts of the cave. He wrote: "*Was das Niveau dieser knochenführenden Ablagerung betrifft, so ist es sehr bezeichnend, dass es auch hier wieder die höchste Stelle des Höhlenarmes ist, in der wir den diluvialen Lehm mit den Bärenresten finden. Soweit es möglich war, dieses Niveau zu bestimmen, so liegt dasselbe 10 bis 12 Meter unter dem Höhleneingange, also in derselben Höhe, wie die knochenführenden Lehmterrassen in „Hochstetter's Schatzkammer"*."
Starting from these higher positions bones and teeth were washed out of the sediment and were relocated into lower areas by fluviatile and gravitational transport. This is a suitable explanation for the numerous bear remains, which were found on the surface of the loams around "Ölberg" and lake "Tiberias". Nowadays there are only a few fossil remains in place, as for instance, a cranium fixed on the wall and a mandible of cave bear, which is situated underneath a huge slab and is frequently shown to visitors in the course of guided tours.
The excavations in the years 1999 and 2001 fully confirmed Hochstetter's view. The fossil-bearing layer consists of dark and only slightly compacted loams, which contain vertebrate remains as well as rounded limestones. This layer lies transgressively above a layer of light-brown loams, which is partly up to 12 m thick. In "Hochstetters Schatzkammer" there is a thin layer of sinter positioned in between these two packets of loam, which is missing in "Kittls Bärenhöhle".

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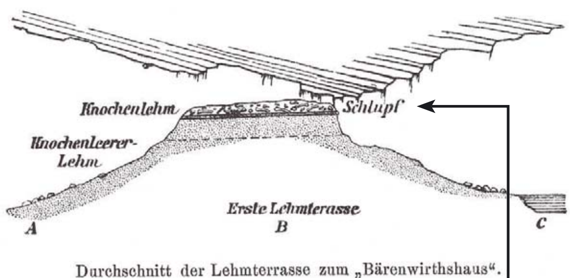
Lab. No.	Sample No.	^{14}C-ages BP	1 σ		Material	Site	Calibrated Age
			+	–			
VERA-2187	KJ-170	740	35	35	Charcoal	Kittls Bärenhöhle	1210 AD – 1300 AD
VERA-2189 *)	KJ-205	32.550	220	220	Cave bear bone	Kittls Bärenhöhle	37.877 BP (95.4%) 36.528 BP
VERA-1289	KJ-48B	44.800	1800	1400	Cave bear bone	Ölberg	***)
VERA-1289 repeated in 2011		47.000	2700	2000			
VERA-1291	KJ-43	45.000	1900	1600	Cave bear bone	Monumentenhügel	***)
VERA-2188	KJ-204	46.500	1200	1100	Cave bear bone	Kittls Bärenhöhle	***)
VERA-1287 **)	KJ-7B	46.700	2400	1800	Cave bear bone	Monumentenhügel	***)
VERA-1287 repeated in 2011		41.200	1400	1200			47.795 BP (95.4%) 42.963 BP

Table 1: Radiocarbon datings of Križna jama. *) According to laboratory notes from 2001 the collagen yield of this sample was in the 0.1% range. The age of this sample has to be treated with caution and must be considered as minimum age. **) Collagen yield below 1% of the initial sample amount. ***) The calibrated time range exceeds the time range spanned by the IntCal09 calibration curve.

Figure 1: **Right**: Schematised cross-section through the sediments of the "Bärenwirtshaus" close to and above lake "Tiberias". Illustration was taken from Hochstetter (1881). **Explanation**: **Knochenlehm** – bone-bearing loam, **Knochenleerer Lehm** – sterile loam, **Erste Lehmterrasse** – first terrace of loam, **Schlupf** – narrow passage; **Below**: Photography of Lake Tiberias and the ascending path, which leads to the "Bärenwirtshaus". The line indicates the position of the "Schlupf" on Hochstetter's sketch in real life. Photography: Gerhard Withalm, 2009



The thickness of the fossil-bearing layer varies significantly: In former times, this layer was several meters thick in the area around "Bärenwirthaus", nowadays it is completely missing, see Fig. 1. During the excavation in 1999 two quadrants, M10 and M11, were unearthed in the area close to "Monumentenhügel" and a profile was drawn, see Fig. 2 and 3. The latter shows a very thin fossil-bearing layer with a thickness between 2 and 10 cm, which is intercalated between two layers of sinter. The intercalation of the fossil-bearing layer between the

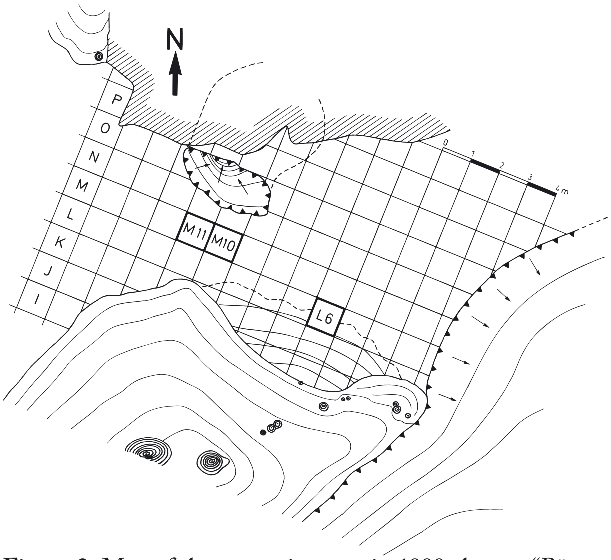


Figure 2: Map of the excavation area in 1999 close to "Bärenwirtshaus".

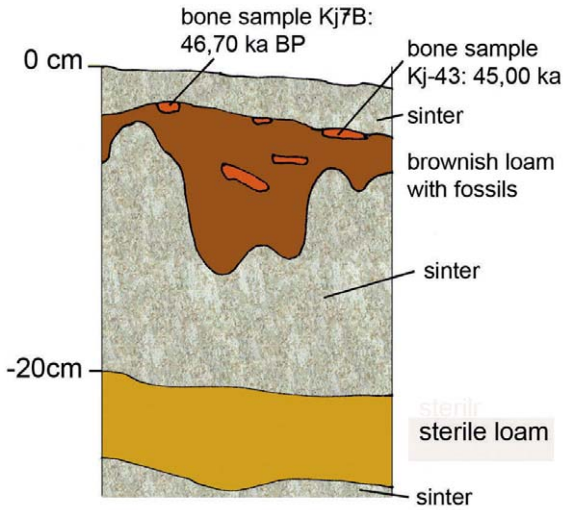


Figure 3: Profile taken during the excavation close to "Monumentenhügel".

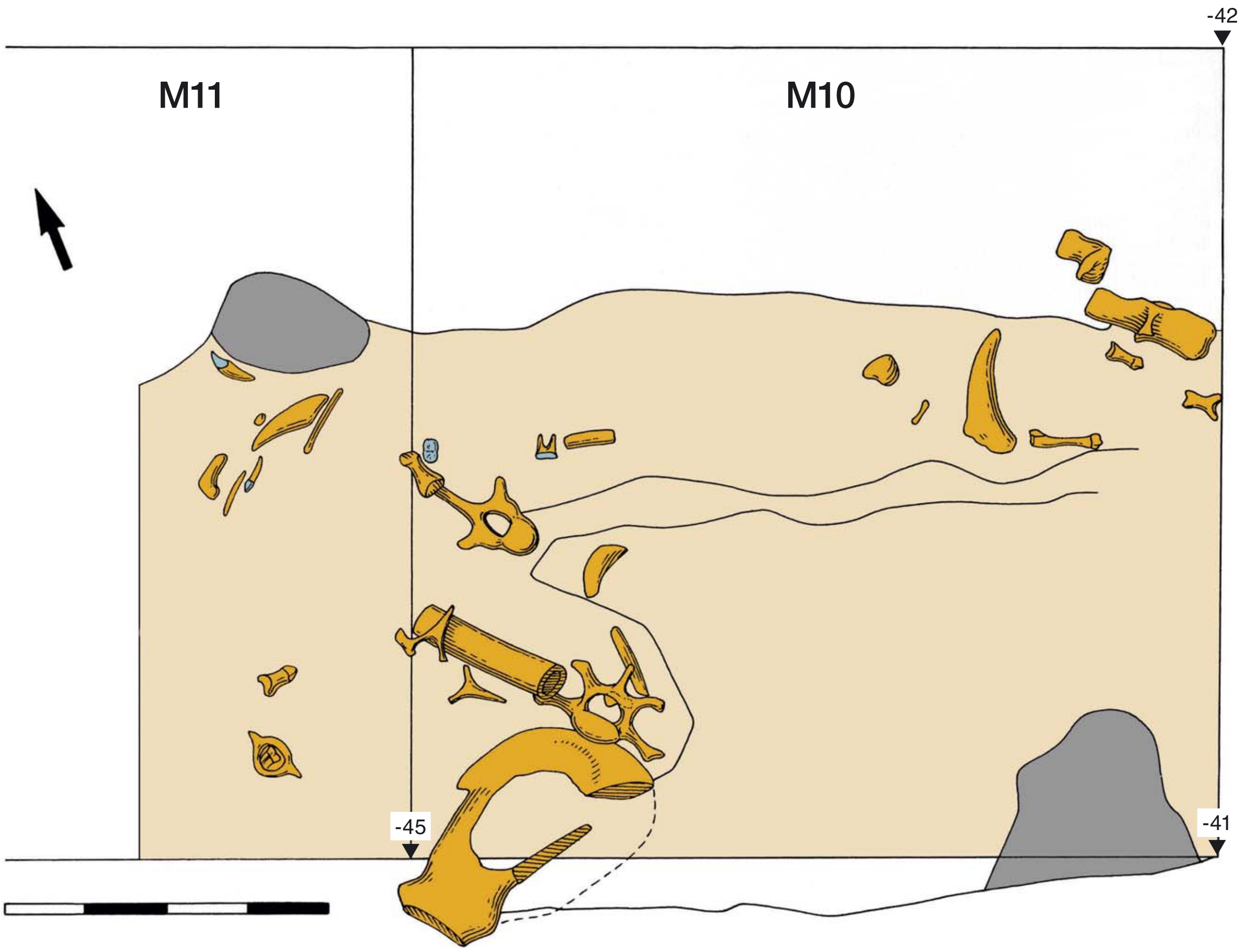


Figure 4: Sketch of quadrants M10 and M11 close to "Monumentenhügel" drawn during the excavation in 1999. Depth indications in cm below NN.

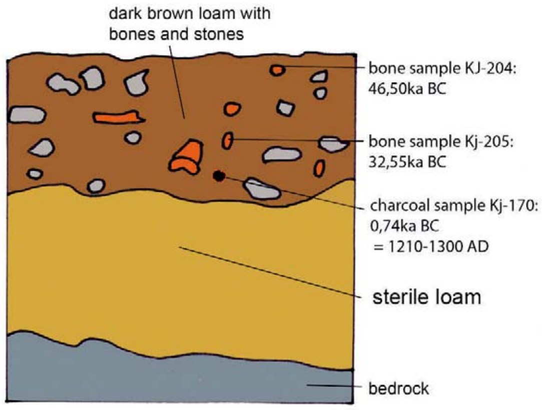


Figure 5: Schematised profile in "Kittl's Bärenhöhle" drawn during the excavation in 2001.

uppermost sinter layer and the surface of the second sinter layer speaks in favour of an allochthonous position of the fossils. Two fragments of cave bear bones situated directly underneath the thin, upper layer of sinter were dated by means of ^{14}C-dating and showed reliable ages between 47 and 45 ka BP, see Tab. 1. A sketch drawn during the excavation in 1999 shows the bony fragments and teeth in a position, which are typical for transport by water, see Figs. 3 and 4.
The profile excavated in "Kittl's Bärenhöhle" during the excavation campaign in 2001, shows the circumstances of sedimentation even better, see Fig. 5.

2. Conclusion

The fossil-bearing layer is situated directly, i.e. without any intercalations above the layer of sterile loam, which is – in turn – situated directly on the solid bottom of the cave. In this part of the cave the thickness of the fossil-bearing layer is between 40 and 50 cm. The fact that all fossil long bones are in allochthonous position is clearly shown by their similar orientation, compare to Pohar (this volume). The cave bear remains from this layer show radiometric ages between 47 and 32 ka BP and are intermingled with Late Holocene charcoal, a fact that clearly shows that relocation and transport of fossil material lasted at least until the medieval. During periods of flood water level the water rose unto the highest parts of the cave, destroyed the original sediments and reshipped cave bear bones and extant charcoal remains together. A relocation of the fossil remains can also be expected for the thick fossil-bearing layer in the "Bärenwirtshaus" of which Hochstetter (1881:17) was convinced that the cave bear remains were auto- and not allochthonous. Based on several observations he concluded: "*In der Kreuzberghöhle liegen die Bärenreste nicht auf secundärer, sondern auf ursprünglicher primärer Lagerstätte.*". The same altitude of the fossil-bearing layer and the similiarity of stratigraphy in "Kittl's Bärenhöhle" speak in favour of Hochstetter's assumption, see Figs. 7 and 8.

Figure 6: Look up the wall nearby the path towards "Bärenwirtshaus" close to "See Tiberias". Photo: Gerhard Withalm, 2009

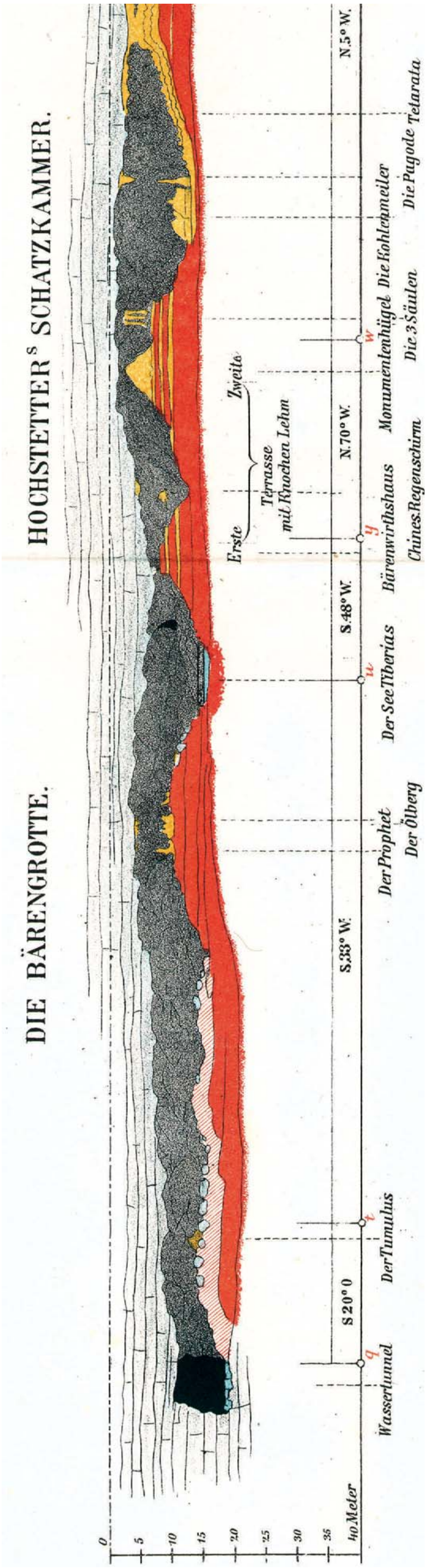


Figure 7: Longitudinal section through a part of Križna jama: Bärengrotte, Hochstetter's Schatzkammer und Seitengrotte E, illustrating the equal levels of fossil-bearing loams in the "Bärenwirtshaus" and "Kittl's Bärenhöhle", compare to Fig. 8. Graphics taken from Hochstetter (1881), survey: J. Szombathy

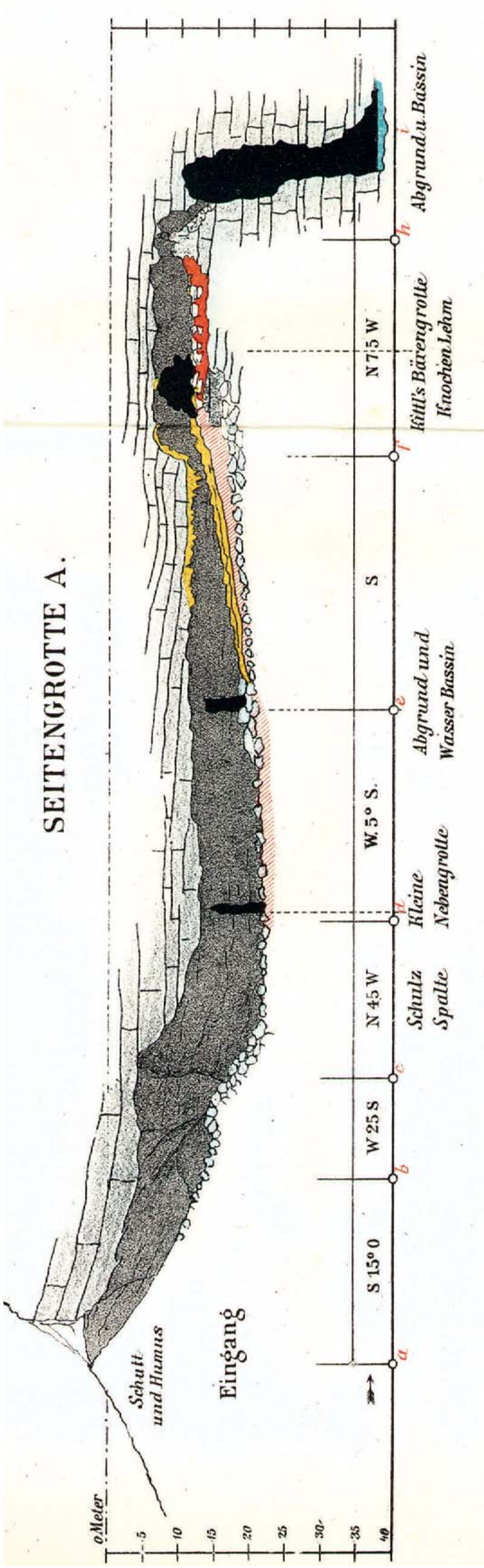


Figure 8: Longitudinal section through a part of Križna jama: Seitengrotte A, illustrating the equal levels of fossil-bearing loams in the "Bärenwirtshaus" and "Kittl's Bärenhöhle", compare to Fig. 7. Graphics taken from Hochstetter (1881), survey: J. Szombathy

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