SBORNÍK NÁRODNÍHO MUZEA V PRAZE
Řada B – Přírodní vědy • sv. 67 • 2011 • čís. 1–2 • s. 35–46

ACTA MUSEI NATIONALIS PRAGAE
Series B – Historia Naturalis • vol. 67 • 2011 • no. 1–2 • pp. 35–46

INTERDISCIPLINARY RESEARCH OF MAGDALENIAN LAYERS IN BALCARKA CAVE (OSTROV NEAR MACOCHA, MORAVIAN KARST)

MIRIAM NÝVLTOVÁ FIŠÁKOVÁ
Institute of Archaeology, Czech Academy of Sciences, v.v.i., Královopolská 147, 612 00, Brno, Czech Republic;
e-mail: miriam@iabrno.cz

ZDEŇKA NERUDOVÁ
Moravian Museum v.o., Anthropos Institute, Zelný trh 6, 659 37, Brno, Czech Republic; e-mail: znerudova@mzm.cz

MARTINA MORAVCOVÁ
State Geological Institute of Dionýz Štúr, Mlynská dolina 1, 817 04, Bratislava 11, Slovak Republic;
e-mail: martina.moravcova @geology.sk

Nývltová Fišáková, M., Nerudová, Z, Moravcová, M. (2011): Interdisciplinary research of Magdalenian layers in Balcarka Cave (Ostrov near Macocha, Moravian Karst). – Acta Mus. Nat. Pragae, Ser. B, Hist. Nat. 67(1-2): 35-46, Praha. ISSN 0036-5343.

Abstract. A preparative archaeological survey was carried out in Balcarka Cave in the Moravian Karst in 2007. As the original archaeological layer known from the research carried out by J. Knies from unique items from the Magdalenian Period were not found, sediments with numerous palaeontological finds were investigated. These finds were analysed from both the archaeological and natural science viewpoint.

■ Balcarka Cave (Moravian Karst), rescue excavation, Late Palaeolithic, palaeontology, seasonality, palaeoecology, use-wear analysis, isotopic study

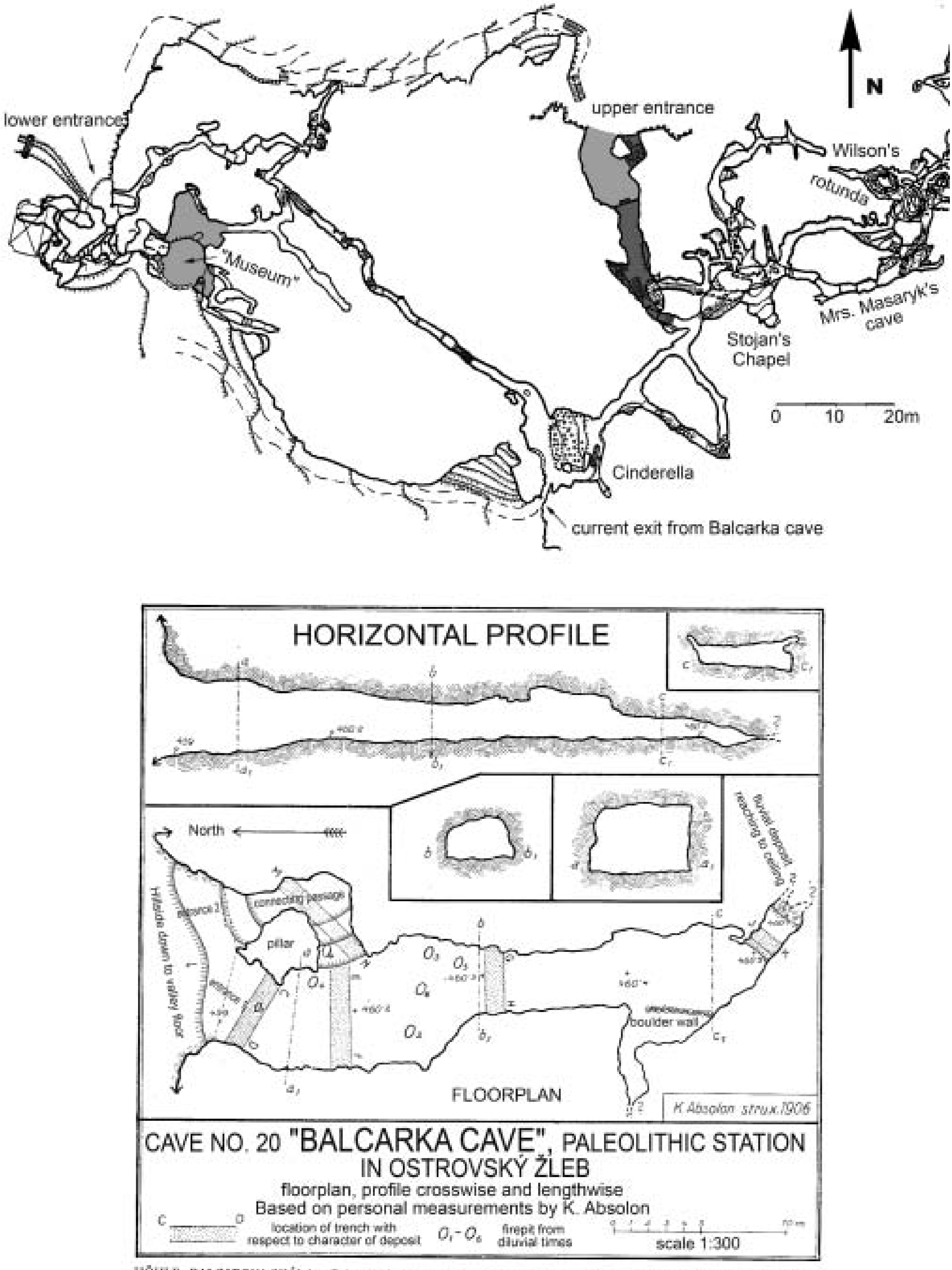
Received October 4, 2010
Issued August 2011

Introduction

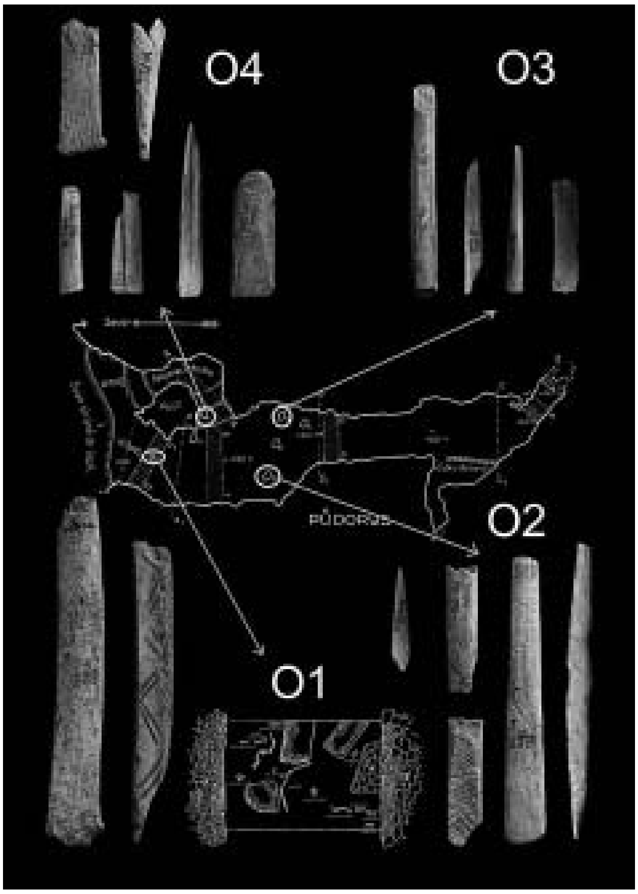
Balcarka Cave (Text-fig. 1) was surveyed at the end of the 19th century by J. Knies (Knies 1900; 1902) and later by local Member of Parliament J. Šamalík, who performed an intensive clean-up in the cave in order to make it accessible to the public (Valoch, 2010). Both surveys were unfortunately poorly documented, using the contemporary methodology, and the original rich find collections were gradually devalued (for details, see Neruda – Nerudová, 2010). Despite this, the collections of the Moravian Museum – Anthropos Institute contained a unique collection of Magdalenian artefacts from the research carried out by J. Knies (Text-fig. 2). In addition to chipped stone industry, there are also numerous osteological material and bone and antler industry, including decorative items. The archaeological material has been published several times in the past (Valoch 1960; 2001). However, as the Anthropos Institute of the Moravian Museum carried out a preparative rescue excavation in 2007 as part of the planned reconstruction of the cave, a new comprehensive assessment was carried out on all the available archaeological and palaeontological finds taking new results into account.

The 2007 research verified the extent of the Magdalenian cultural layer and, where applicable, documented the existence of the Middle Palaeolithic, which is indicated by Knies' find from the left entrance into the Balcarka Cave (Knies 1928; Valoch 1999). It was found during the research that most of the intact sediments had been cleared earlier (Knies 1900, 1902). In some places up to 2 m thick sedimentary sequence had been removed. The presence of the Middle Palaeolithic settlement had not been proved during the research. The remnants of the sediments preserved on the cave walls gave a radiocarbon age, which falls into the Early Gravettian time. The sediments (2007 research) lying below the dated unit are older and probably date from the older Weichselian glacial period (Neruda, 2010).

The chipped stone industry is represented by a fairly small but highly significant Magdalenian collection containing mainly retouched tools (endscrapers, backed bladellet and burins). The backed bladellets, which were hunting tools, and burins and borers as tools for working materials are typical for functionally specialised localities (Nerudová – Neruda 2010). This picture fits exactly with the use-wear assessment of the burins from Balcarka Cave. Despite the intensive post-depositional processes and patination, these burins do indeed show traces of marks caused by contact with hard animal materials (Kufel 2010). Some of the stone raw materials found here, isolated examples of which are contained in the chipped industry, show that there were contacts with various different regions, not only in Moravia



Text-fig. 1. Top: Overall plan of Balcarka Cave indicating the investigated areas (marked in grey). Bottom: Detail of the upper entrance to Balcarka Cave indicating the position of the individual probes and fireplaces investigated by J. Knies. (K. Absolon 1905-11). Adopted from Valoch 2010.



Text-fig. 2. Spatial distribution of artefacts (ground plan of cave by Absolon 1906, plan of fireplace 1 by Knies 1900; photo by M. Rašková Zelinková). Adopted from Nerudová ed., 2010.

itself (rock crystals, chert of Krumlovský les type (Krumlov Forest) and chert of type Olomučany), but also on a macro-regional scale (Cracow-Częstochowa Jurassic silicite, radiolarites from the Vienna and Hungarian territory).

In the context of other finds discovered in the entrance part of the cave by J. Knies (uncovered fireplaces, bone and antler industry), this is an important locality, which represents a temporary station associated with hunting and further processing of dead animals bodies. The settlement of Balcarka Cave is the oldest dated Magdalenian settlement at the territory of the Czech Republic found so far (Neruda 2010).

The principal finds in the collection of osteological material from the rescue excavations carried out in 2007 are the cubs (up to 3 months old – neonatus) of bears *Ursus* ex gr. *spelaeus* (a total of 508 milk teeth have been identified). There are also the reindeer (*Rangifer tarandus*), horse (*Equus* sp.), hare (*Lepus* sp.), fox (polar and red – *Vulpes* icl. *Alopex*), wolf (*Canis lupus*), chamois (*Rupicapra rupicapra*), woolly mammoth (*Mammuthus primigenius*), which was represented by, amongst other finds, the tooth of a young calf, and numerous mammalian microfauna, which has not yet been analysed. Based on the nature of these finds we can state that the cave was the hibernaculum of cave bear females (November – April), which eliminates its usage by other species (Seitl, 2010).

Materials and methods

Materials

Studied material is coming from Knies excavation and from rescue excavation in 2007. All fossil materials are deposited in Anthropos Institute (Moravian Museum).

For study of seasonality 20 fragments of mandibles, 10 fragments of maxilla and 60 isolated teeth of reindeer were used. For study of microstructructures of dental cement reindeers molars, molar and caninus of wolfs and caninus of polar fox were used.

For isotopic research we used two teeth of *Rangifer tarandus*, two teeth of *Equus* sp. and one tooth of *Ursus* sp – see Table 1. The age of these samples was older than 28 360 ± 140 uncal. BP (OxA-18495 Balcarka 2007-2 Sample 11, charcoal). For isotopic research we used bulk samples from teeth enamel. In this research we did not used multi serial sampling of the teeth for isotope analyses. All teeth belongs to an adult individuals. Carbon isotope analyses ($^{13}C/^{12}C$) served for palaeodiet and for palaeoenvironmental reconstruction. Oxygen isotopes ($^{18}O/^{16}O$) were used for palaeotemperature reconstruction. Studied material is deposited at the Moravian Museum (Brno, Czech Republic).

Methods

Oxygen isotope composition of bioapatite as a palaeoclimatic proxy

Oxygen isotopic ratios were used primarily in determining drinking habits and physiological processes and they can yield valuable information, for example, about local rainwater (Wang et al., 1993).

Land mammals precipitate their skeletal parts at a constant temperature of ~37 °C. The oxygen isotope composition of their bioapatite is dependent on the isotopic composition of the animal's body water (Longinelli, 1984; Luz et al., 1984). The $\delta^{18}O$ value of body water, in turn, is related to the isotopic composition of ingested environmental waters, which usually correspond to the mean $\delta^{18}O$ value of regional precipitation. The isotopic composition of oxygen in meteoric waters correlates with regional mean annual temperatures (Dansgaard, 1964). It follows that the oxygen isotope composition of fossil skeletal material contains

Tab. 1. Character and finding conditions of the samples used for isotope analyses.

species	material	tooth type	sample	square	depth (cm)	sediment
Equus sp.	enamel		E B1	21/CH da	126	2A (surface)
Equus sp.	enamel	I	E B2	22/I ca	100 – 110	2
Rangifer tarandus	enamel	P2 inf. dex.	RT B1	20/j	under the	backfill
Rangifer tarandus	enamel	M1 inf. sin.	RT B2	2CH cb	110 – 120	2
Ursus sp.	enamel		US B1	23/6 da	110 – 120	2

information on past atmospheric temperatures in terrestrial environments. Tooth enamel is generally considered most resistant of all skeletal material to post-depositional alteration, and it represents the preferred material for isotope research (e.g. Ayliffe et al., 1992, 1994; Bryant et al., 1994, 1996; Koch et al., 1997; Lee-Thorp and Sponheimer, 2003; Zazzo et al., 2004).

Carbon isotope composition of bioapatite as a palaeodiet and palaeoenvironmental proxy

Traditional methods of reconstructing the diet of extinct mammalian herbivores rely heavily on extant analogues and include measures of molar occlusal morphology (Kay, 1975) and crown height (Webb, 1983; Janis, 1984; Janis et al., 2000), evidence from tooth enamel microwear (Walker et al., 1978), measures of cranial shape and masticatory functional anatomy that correlate with dietary preferences (Solounias et al., 1988; Janis, 1990), and phylogenetic affinity (Vrba, 1985). These techniques offer an interpretation of animal diet, but they cannot reflect the whole possible diet (Feranec, 2004). Recently, geochemical measurements of mineralised tissues of fossil mammalian herbivores have provided a new source of data on diet that is effectively independent of comparisons with extant analogues (van der Merwe, 1982; Sillen, 1986; Lee-Thorp and van der Merwe, 1987; Sillen and Lee-Thorp, 1994; MacFadden et al., 1999; Passey et al., 2002).

Processes and formulas used

For determination of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios we used the methodology of McCrea (1950). Powdered sample was dissolved under vacuum in 100% H_3PO_4. The samples are equilibrated at room temperature for 1 day. Samples are then measured against the international or laboratory standard (Carresian marble) using the Finnigan MAT 251 mass spectrometer. External precision of determination for $\delta^{18}O$ is better than 0.05‰.

The raw data gave oxygen isotope ratios in tusk dentine carbonate relative to Vienna Pee Dee Belemnite (VPDB). First, this value was converted back to the raw ratio of ^{16}O to ^{18}O.

$$R\ sample = (\delta^{18}O/1000 + 1) \times RVPDB\ standard$$

This raw value was then re-calibrated to the VSMOW standard.

$$\delta^{18}O = (Rsample/RVSMOW\ standard - 1) \times 1000‰$$

$$^{16}O/^{18}O\ VPDB = 2.00672 \times 10^{-3}$$

$$^{16}O/^{18}O\ SMOW = 2.0052 \times 10^{-3}$$

Isotope data received from the laboratory of the Czech Geological Survey represent results from structural carbonate in hydroxyapatite. It was necessary to convert dentine carbonate values of the tusk to phosphate values in order to calculate $\delta^{18}O$ of drinking water. We used these formulas for this calculation:

$$\delta^{18}O_p = \delta^{18}O_c (\pm 1.3) - 8.3 (\pm 0.7) / 1.02 (\pm 0.04)$$
(for *Equus caballus* and *Rangifer tarandus*)
(Bryant et al., 1996)

The relationship between drinking water $\delta^{18}O$ and enamel/dentine apatite $\delta^{18}O$ varies between species due to metabolic differences and the amount of water intake. Studies by Huertas et al. (1995) and D´Angela – Longinelli (1990) have produced formulas for horses and reindeers:

$$\delta^{18}O_w = [\delta^{18}O_p - 22.6]/0.71$$ (for *Equus* sp.)
(Huertas et al., 1995)

$$\delta^{18}O_w = (\delta^{18}O_p - 25.55)/1.13\ (r = 0.99)$$
(for *Rangifer tarandus;* D´Angela – Longinelli 1990)

These formulas were used for calculation of $\delta^{18}O_{drinking\ water}$.

We calculated palaeotemperature according to the relationship provided by Rozanski et al. (1992):

$$\delta^{18}O_w = (0.59 \pm 0.09) \times T - 14.35;\ r^2 = 0.49$$

Note

SMOW = Standard Mean Ocean Water (R = 0.0001558)
PDB = Pee Dee Belemnite (R = 0.0112372)
$\delta^{18}O_p$ = oxygen isotope composition of phosphate fraction of the tooth
$\delta^{18}O_c$ = oxygen isotope composition of carbonate fraction of the tooth
$\delta^{18}O_w$ = oxygen isotope composition of drinking water

Seasonality

In order to determine death age, or season, classic zooarchaeology now primarily uses methods based on epiphyses fusion (Hufthammer, 1995), the annual growth of tooth cement (Ábelová, 2005a, b; Curci and Tagliacozzo, 2000 and Nývltová Fišáková, 2007), tooth eruption (Miller, 1974; Spiess, 1979; Pike-Tay et al., 2000), tooth abrasion (Enloe and Daniel 1997; Enloe-Turner 2004; Pike-Tay *et al.* 2000) and the tooth crowns height (Bouchud 1954, 1966; Miller 1974; Spiess 1979). The height of the milk-tooth crowns of the fourth premolars (*premolar* dp4) – Enloe (1993) was used as additional method.

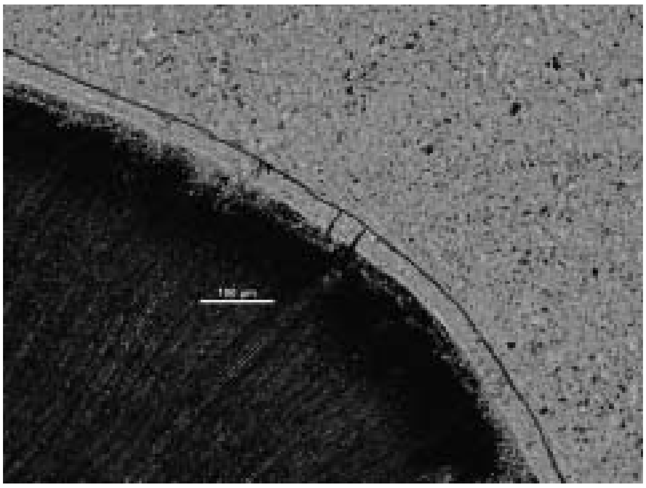
Results

The method based on tooth eruption could have been used for only two right lower mandibles (*mandibula*) of reindeers. On the mandible of the first specimen of reindeer it is evident that the second molar (*molar* –m2) started to erupt, which according to Spiess (1979) erupts between the age of 10 and 15 months. The death season can thus be dated to sometime between the middle of March and the middle of August, so we can assume that these animals were hunted in the spring to summer. According to Pike-Tay et al. (2000) the m2 erupts before the age of 12 months, which would mean the turn of May and June (Rašková Zelinková 2010). The death season of this specimen was refined using the method based on the height of the milk-tooth crown of the fourth premolar dp4, which implies the age of 12 months. On the second specimen p4 was erupting at the time of death, which, according to Spiess (1979), erupts between the age of 22 and 29 months and according to Pike-Tay et al. (2000) after 24 months. In general the erupting premolars rule out the possibility of death between November and February. The lower mandible of the second specimen shows that the animal died between the middle of March and the middle of September (Rašková Zelinková 2010).

Maxillas of reindeers were also studied for completeness (Rašková Zelinková 2010). Two specimens were found to have third and fourth milk premolars (*premolares* – DP3 and DP4. If the eruption pattern of the maxillas is similar to the pattern of the mandibles, as claimed by Spiess (1979), these specimens did not live past the age of 22 months, the age when permanent premolars begin to erupt. Analysis of abrasion of the tooth crowns found five left and two right lower mandibles of specimens between the age of one and two years, i.e. of at least five specimens. On four of the left mandibles the age was estimated to be between 2 and 3 years and one left and one right mandible belonged to a individual more than 3 years old (Rašková Zelinková 2010).

Analysis of the tooth crown height was possible on 12 lower mandibles (9 left and 3 right). Based on the analysis the age of these animals ranged from 2 to a maximum of 9 years, while the animals were hunted from spring to the beginning of autumn (Rašková Zelinková 2010).

Thin sections of the teeth roots of mammals were used to determine seasonality. The individual types of animals and teeth, including localisation of where they were found, their assumed age and death season are shown in Table 2 and Text-fig. 3.



Text-fig. 3. First lower molar (M_1 dex) of reindeer (*Rangifer tarandus*). Photo by M. Nývltová Fišáková (polarisation microscope Nikon LV100VL).

The collection contained a relatively small number of postcranial skeletal remains, while axial skeletal parts were lacking completely; as regards the appendicular skeleton, finds primarily comprised autopodia, as well as one diaphysis of a radius, 3 distal epiphyses of tibia, 12 fragments of the articular heads of femurs and a fragment of a humerus (Rašková Zelinková 2010). The resulting ages of hunted reindeers are shown in Table 3.

Palaeoecology and climate reconstruction

An important tool allowing us to reconstruct short-term climate fluctuations is the isotope analysis of biominerals. After an animal dies it is possible to use isotope analyses to study its tissue and thus obtain valuable palaeoenvironmental data (Koch *et al. 1994*). Using stable isotopes to reconstruct the palaeoenvironment and palaeodiets in the Late Pleistocene has been proven to be one of the most effective methods (Ábelová 2007, 2008; Ayliffe et al. 1992; Bryant et al. 1994; Bocherens et al. 1996; Cerling and Harris 1999; Driessens and Verbeeck 1990; Ehleringer and Cerling, 2002; Galiová et al. 2010; Moravcová (Ábelová) and Sabol, 2009; Nývltová Fišáková 2008; Nývltová Fišáková et al. 2009). Based on analyses of the isotope composition of mammalian tissues it is possible to reconstruct the palaeoenvironment, palaeotemperatures, diet and migrations of fauna without having to derive these data from actual finds of fauna at archaeological sites.

Carbon isotopes ($^{13}C/^{12}C$) were used to determine palaeodiets and also for the indirect identification of vegetation cover. Oxygen isotopes ($^{18}O/^{16}O$) were used to reconstruct palaeotemperatures.

Samples of enamel from two teeth of a reindeer (*Rangifer tarandus*) and a horse (*Equus* sp.) and sample of tooth enamel of a bear (*Ursus* sp.) from the rescue excavations in Balcarka Cave were used for isotopic analyses. The teeth belonged to adult specimens. The diet and palaeoecology of these species is very well known from analogies of their living equivalents. Reindeers and horses still live today, although in different climatic conditions.

The $\delta^{13}C$ values from the tooth enamel of the horse and reindeer from Balcarka indicate that these animals lived in a steppe environment (Table 4 and Graph 1).

The palaeotemperature calculated on the basis of the $\delta^{18}Op$ of the tooth enamel from the horse and reindeer ranges from around 6.3 to 10.6 °C, which probably represents rather the summer temperature, than the annual mean temperature of this part of Last Glacial (Table 3).

Table 2. Localisation, tooth type and death season of individual species of animals from the Balcarka Cave.

Lokalisation	Species	Anatomical part	Sesonality of Death	Tooth Age
102Ab	*Vulpes lagopus*	*Caninus* (C1)	V-VII	1,5 years
108A, ok-21719	*Canis lupus*	*Caninus* (C1)	X-XII	2,5 years
108A, 207A, ok-21718	*Canis lupus*	*Molar* (M1)	V-VII	4,5 years
mandible without ID number	*Rangifer tarandus*	*Molar* (M1)	V-VII	5,5 years
without ID number	*Rangifer tarandus*	*Molar* dx. (M1)	V-VII	6,5 years
without ID number	*Rangifer tarandus*	*Molar* dx. (M2)	V-VII	3 years
without ID number	*Rangifer tarandus*	*Molar* sin (M1)	X-XII	3,5 years

Table 3. Age composition of prey based on epiphyses accretions.

Anatomical part	Age	MNI	NISP
femur prox.	< 36 month	1	1
	36 – 48 month	4	4
tibia dist.	< 18 month	1	1
	> 30 month	1	1
phalang I, II	< 6 month	1	2
	6 – 18 month	3	22
	> 18 month	4	32
metacarpus	< 18 month	1	1
	< 30 month	3	4
	> 30 month	4	7
metatarsus	18 – 30 month	1	1
calcaneus	18 – 42 month	1	1

Discussion

Analyses of eruptions, tooth abrasion and the microstructures of tooth cement have shown that Balcarka Cave was a seasonal settlement, i.e. that people lived there in spring and in autumn. Seasonality clearly related to the spring and autumn migrations of the herds of reindeer was found by Nývltová Fišáková (2008) to be important especially during the Late Gravettian (Willendorf-Kostenki Phase) at the turn of OIS 3/2. General climate cooling and vegetation changes (the transition from a park landscape for Gravettian – OIS 3 to cold steppes or tundra for Magdalenian – OIS 2) were determined on the basis of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ isotope ratios from the bones and teeth of large mammals (Nývltová Fišáková, 2008; Richards and Hedges, 2003). These dramatic changes forced reindeers to migrate in the course of OIS 2, followed by the Magdalenian hunters. During the Evolved Gravettian (during the late part of OIS 3) the situation was different. Analyses of strontium isotope $^{87}Sr/^{86}Sr$ ratios have shown that reindeers did not migrate during Evolved Gravettian time (OIS 3), and were what is known as the forest forms of reindeer (Nývltová Fišáková, 2008). This is in concordance with the Evolved Gravettian large settlements that were inhabited throughout the year, with networks of seasonal hunting camps (Nývltová Fišáková, 2007).

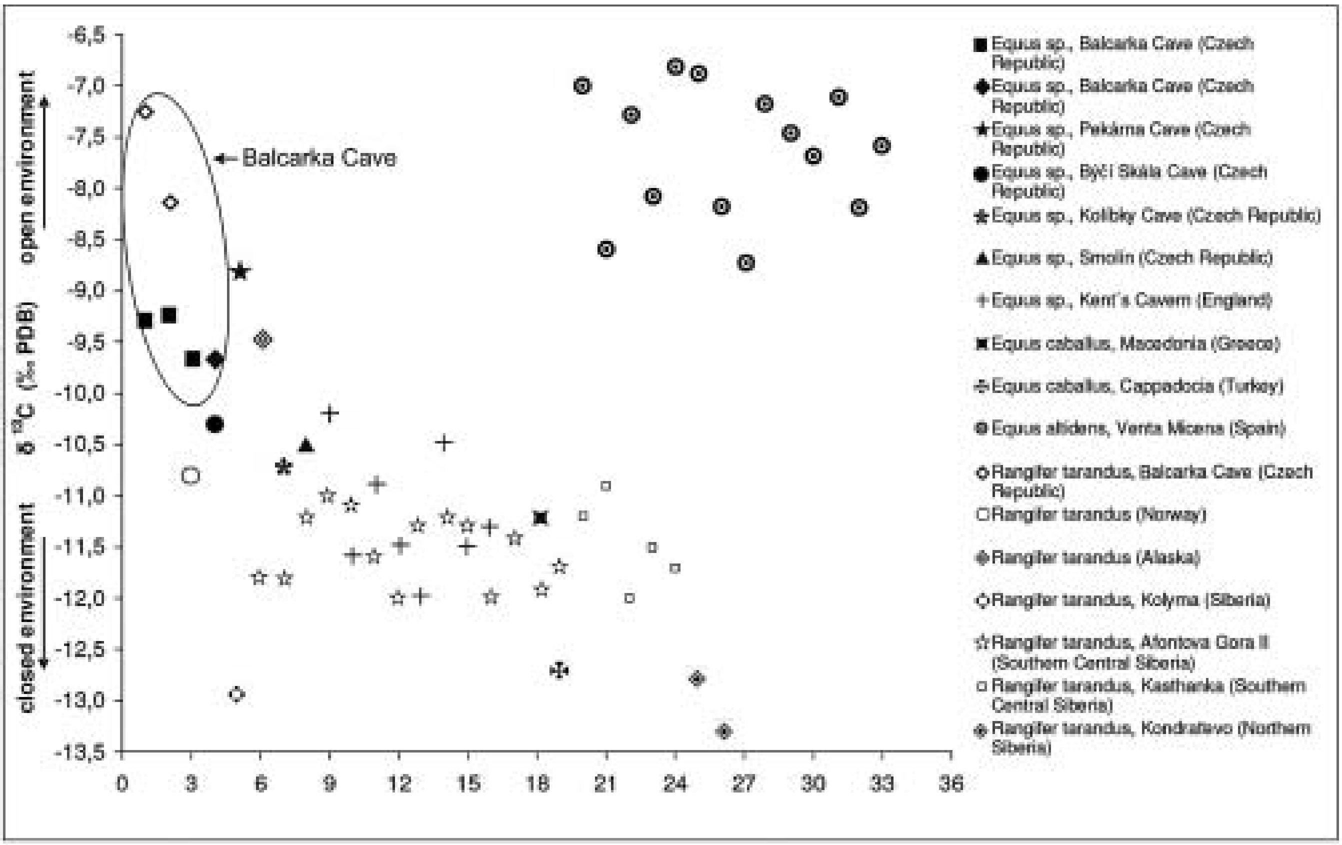
Text-fig. 4. Lower mandible of young individual of reindeer (4 month year old). 2. Lower mandible of reindeer 7,5 year old. 3. Lower mandible of reindeer 8 year old. 4. Lower mandible of reindeer with starting eruption of second molar (M2) and milk molars – age of ~12 months. Photo by M. Rašková Zelinková). Adopted from Nerudová ed., 2010.

Regarding the demography of these prey, it was found that the animal ages varied widely, ranging from young just a few months old individuals to specimens that were eight

Table 4. Results of isotope analyses of carbonate from tooth enamel and converted values of isotope ratios and palaeotemperatures for the fossil horses, reindeers and bear from Balcarka Cave.

Sample	$d^{13}C$	$d^{18}O_c$	$d^{18}O_c$	$\delta^{18}Op$	$\delta^{18}Ow$	temperature
	(‰ PDB)	(‰ PDB)	(‰ SMOW)	(‰ SMOW)	(‰ SMOW)	(°C)
***Equus* sp.** EB 1	-9,29	-6,48	24,23	15,61	-9,84	7,6
***Equus* sp.** EB 1 repeated	-9,25	-6,37	24,35	15,73	-9,67	7,9
***Equus* sp.** EB 2	-9,67	-7,02	23,68	15,07	-10,6	6,3
Rangifer tarandus RT B1	-7,23	-6,3	24,41	15,79	-8,64	9,6
Rangifer tarandus RT B2	-8,14	-5,72	25,01	16,38	-8,12	10,56
***Ursus* sp.** US B1	-10,6	-2,45	28,38	19,6	-	-

Note: Values relative to the SMOW (δ18O (‰ SMOW)) standard are determined from the measurements and not the standard converted PDB.
δ18Oc = isotope ratio value 18O/16O of the carbonate element of the enamel
δ18Op = isotope ratio value 18O/16O of the phosphate element of the enamel
δ18Ow = isotope ratio value 18O/16O of the water (which the animal drank)



Graph 1. δ^{13}C of the teeth enamel of *Equus* sp. and *Rangifer tarandus* from Balcarka Cave compared with: δ^{13}C values of the horse *Equus* sp. from the Czech Republic (Balcarka 13,930 BP; Pekárna 12,940 BP; Býčí skála 12,910 BP; Kolíbky 12,680 BP; Smolín 8,315 BP; Ábelová, 2008); *Equus caballus* from Greece and Turkey (recent) (Bocherens, 2000); England (28,000–39,600 BP) Bocherens et al. (1995); *Equus altidens* from Spain (1.3 Ma) (Palmqvist et al., 2003); δ^{13}C values of the reindeer *Rangifer tarandus* from Norway, Alaska, Siberia (recent) (Bocherens, 2000), Southern Central Siberia (Afontova Gora II. 13,000––15,000 BP; Kasthanka 21,000 BP) and Northern Siberia (Kondrat'evo age unknown) (Iacumin et al., 2000).

years old, while the majority of the animals hunted were between 6 and 8 years old. Considering the fact that the mortality curve does not follow the natural model, there was a certain degree of human selection (Rašková Zelinková, 2010).

The δ^{13}C values from the carbonate fraction of the horse samples studied are characteristic for animals living on C3 photosynthesising plants. When we compare the δ^{13}C isotope values of the hydroxyapatite of the horse enamel from Balcarka (δ^{13}C = –9.25 to –9.67‰) with data from other sites in Czech Republic (Býčí skála Cave, Smolín and Kolíbky) we find out that data from Balcarka Cave are the highest. This point to a more open landscape before 28,000 years BP than during the Late Glacial or the Holocene (Graph 1).

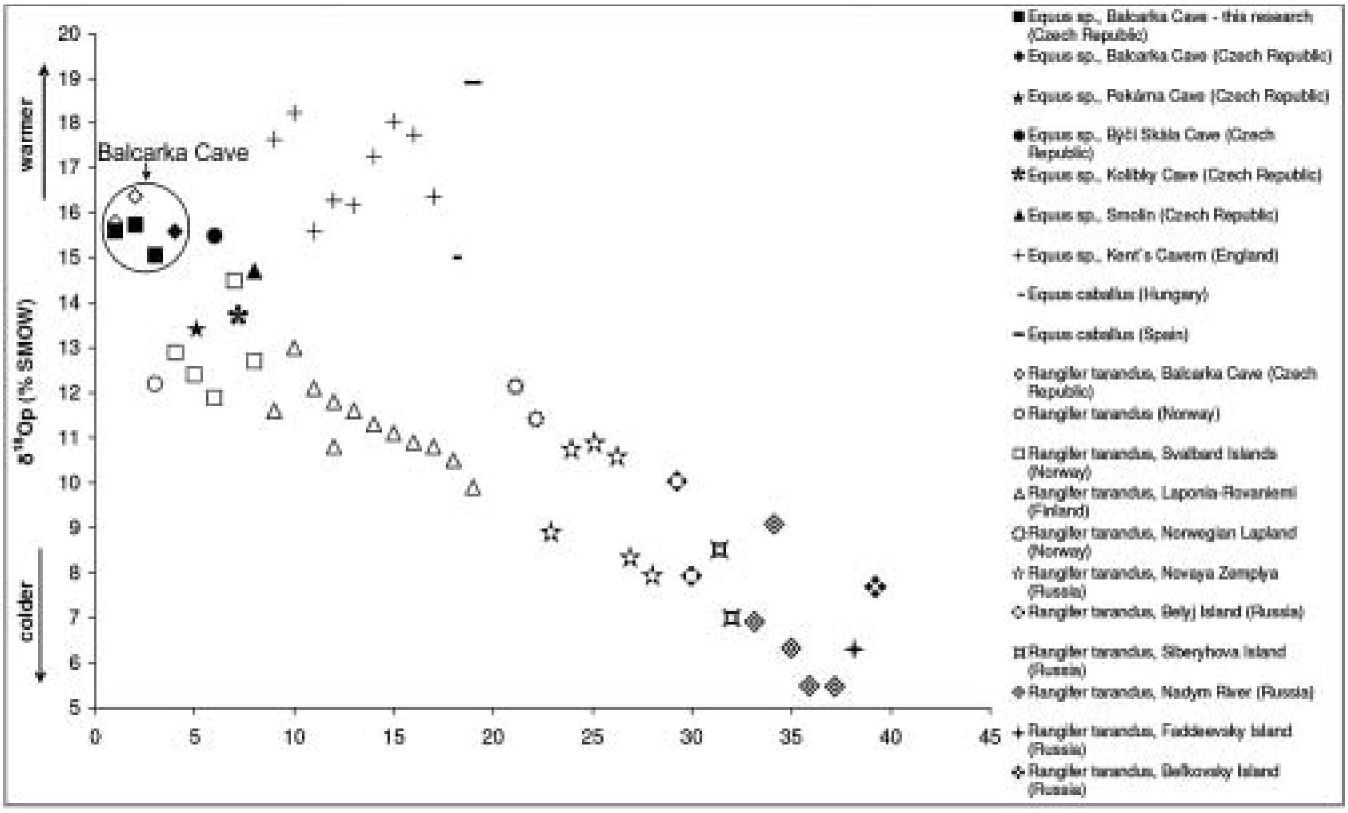
Higher δ^{13}C values in the reindeer studied (–7.23 to –8.14‰) compared to the values obtained from the horse (–9.25 to –9.67‰) may be explained by consuming of mosses by reindeers (Table 3, Graph 1) – (Moravcová (Ábelová), 2010).

δ^{13}C isotope values from studied reindeer teeth from Balcarka Cave are most positive (except of values from *Equus altidens* from Venta Micena – Spain). This also point out that these animals lived in an open area.

It is not possible to make a more detailed specification of the diet of these animals in terms of the species composition of the plants using the results of the isotope analysis. The δ^{13}C value of the bear (δ^{13}C = –10.6‰) is lower than the values from the studied horse and reindeer. The lowest difference in δ^{13}C values detected between the bear and horses is 0.93‰. This difference is not as high as described by Bocherens et al. (1994; 1995) and Bocherens (2000), but confirms the conclusions about the difference in the δ^{13}C values of hydroxyapatite between herbivores and carnivores (including bears). All the δ^{13}C data from the hydroxyapatite of the bear tooth enamel higher than –12‰ were given after Bocherens (1991) as being the result of alteration of the sample. It is very likely that this was an altered sample from which the bear's palaeodiet cannot be reconstructed. Based on isotope analyses of carbon isotope ratios, these species of fauna from Balcarka Cave lived in an open steppe environment.

On the basis of calculations it was found that the δ^{18}Ow values of the water, which the studied horses drank, as derived from the δ^{18}Op values of tooth enamel ranged from –9.67 to –10.6‰ and for the reindeers from –8.12 to –8.64‰ (Graph 2). These values correspond to the temperature of between 6.3 and 10.6 °C (Table 3) – (Moravcová (Ábelová), 2010). The present temperature in the Moravian Karst ranges from 6.5 to 8.4 °C (CHKO Moravský kras, 2009).

The palaeotemperature calculated on the basis of the δ^{18}Op of the horse and reindeer enamel (6.3–10.6 °C) probably may represent the temperature of summer months of



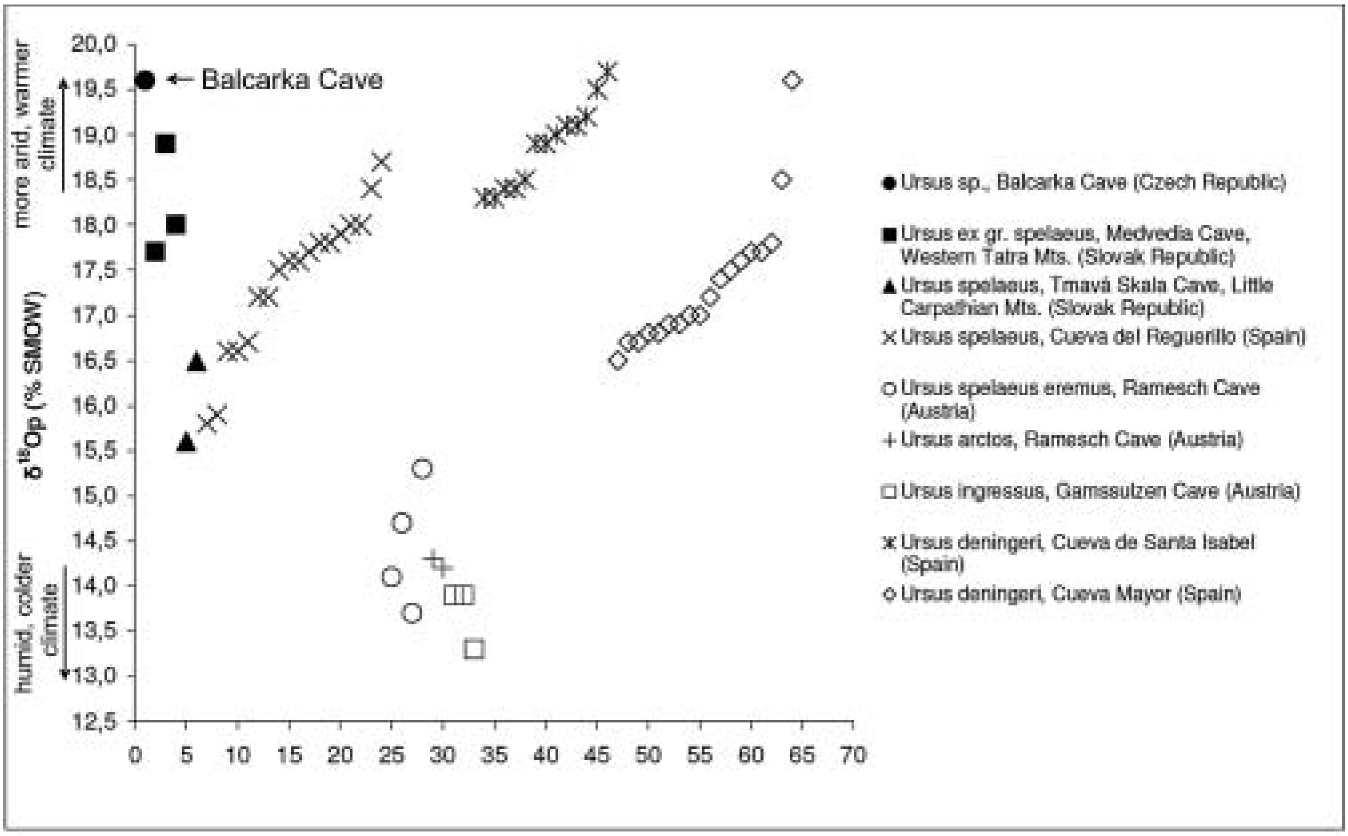
Graph 2. δ^{18}O of the enamel from the teeth of *Equus* sp. and *Rangifer tarandus* from Balcarka Cave compared with: δ^{18}O of the enamel and dentine of *Equus* sp. from the Czech Republic (Balcarka 13,930 BP; Pekárna 12,940 BP; Býčí skála 12,910 BP; Kolíbky 12,680 BP; Smolín 8,315 BP; Ábelová, 2008); England (Kent´s Cavern 35,000 BP; Bocherens et al., 1995); *Equus caballus* from Hungary, and Spain (recent); (Sánchez-Chillón et al., 1994); δ^{18}O of the enamel and dentine of *Rangifer tarandus* (recent); Norway, Finland and Russia (Iacumin et al. 1996).

this time period. But this conclusion is only hypothetical, because we did not take multi serial samples from each teeth, instead this we take bulk sample from each tooth. If the palaeotemperature calculated on the basis of isotope analyses of reindeer tooth enamel represented the average annual temperature that would make it higher than some studies of the period in question have assumed. This difference in the palaeotemperatures calculated on the basis of δ^{18}Op of reindeer enamel can be explained by the fact that the reindeer migrated from warmer climates further south. Nowadays reindeer are migrating herd animals, which cover hundreds if not thousands of kilometres every year. During their migrations the recent reindeers travel the greatest distances of all land mammals. They can cover up to 5,000 kilometres a year. The greatest migrations occur during spring and autumn (Geist and Baskin, 1990). Therefore, the calculated palaeotemperature may be of a regional nature, reflecting the palaeotemperature of the wider area, as the migrating animals drank water of varying isotopic composition, from various different water sources reflecting a variety of palaeotemperatures (e.g., the hot springs around Předmost near Přerov, Napajedla, etc.). *G3

For bears there is so far no conversion formula for calculating δ^{18}Ow from δ^{18}Op, which means that at present it is not possible to convert the oxygen isotope value from phosphate or carbonate into the oxygen isotope values of the water, which the bear drank when it was alive. Therefore, our data are compared directly with the δ^{18}Op values of bear enamel from a variety of localities from Europe (Graph 3). When we compare our results for the δ^{18}O of bear tooth enamel with the results obtained from other researches, it is clearly evident that our values are some of the highest (Graph 3). From these comparisons and high values it is apparent that the specimen in question lived in a relatively warm environment. However, as they are derived from just one sample, our conclusions must remain preliminary, as the only one measurement may lead to erroneous interpretations.

Conclusion

The interdisciplinary research in Balcarka Cave has resulted in two major findings: besides the aforementioned archaeological analyses, we bring new information about how the cave was used by fauna. The interdisciplinary analysis of the original (Magdalenian) collection (coll. J. Knies) has resulted in the following: study of the industry from hard animal material has shown that the cave was used in spring and autumn, which is also confirmed by analysis of eruptions, abrasion and accretions of tooth cement. Also, the method in which the main prey (the reindeer) was cut up and used indicates that the cave was used for short periods, but repeatedly as a transitional hunting-processing site. This function is also corroborated by technological and typological analysis of the chipped stone industry of the Magdalenian artifacts found there. Isotopic analyses of the teeth of reindeers, horses and a bear have shown that these animals lived in an open steppe habitat. The temperature calculated



Graph. 3. δ^{18}O of the enamel and dentine of *Ursus* sp. from Balcarka Cave compared with the δ^{18}O of the enamel of *Ursus spelaeus* from Slovak Republic – Tmavá skala Cave (more than 35,000 BP) (Ábelová, 2008); *Ursus* ex gr. *spelaeus* from Slovak Republic – Medvedia Cave (most likely more than 46,000 BP) (Moravcová [Ábelová], Sabol, 2009); *Ursus spelaeus eremus* from Austria – Ramesch Cave (43,700 ± 1,270 BP to more than 49,900 BP, *Ursus arctos* from Austria – Ramesch Cave, *Ursus ingressus* from Austria – Gammssulzen Cave (41,060 ± 920 to 47,300 ± 1,970) (Bocherens et al., 2011). *Ursus spelaeus*, Cueva del Reguerillo (820 m a.s.l., 90,000–60,000 BP), *Ursus deningeri*, Cueva Mayor (1022 m a.s.l., 350,000 BP), (*Ursus deningeri*, Cueva de Santa Isabel (220 m a.s.l., 350,000–200,000 BP) from Spain Reinhard et al, 1996).

from oxygen isotopes is higher than the indicated average temperatures for this period and is even higher than the mean annual temperature in the Moravian Karst in the present day. This difference is probably caused by the migration of reindeers and horses or represents rather the average temperature of summer months at that time.

Acknowledgements

The research in Balcarka Cave in 2007 was carried out with the support of the Moravian Karst Cave Administration and the Nature Protection Agency of the Czech Republic; the results were supported by grant project Moravian Museum v.o. MK000094862. The study was supported by grant GA AV ČR KJB800010701 – "Hunting Strategies of the Upper Palaeolithic Hunters" and the research project of the Archaeological Institute of Brno, v.v.i. AV ČR No. AVOZ80010507.

References

Ábelová, M. (2005a): Dental cementum of bears (Ursidae) – possibilities of microscopic study. Neue Forschungen zum Höhlenbären in Europa. – Naturhistorische Gesellschaft Nürnberg e.V., Abhandlung Band 45/2005, 11–18.

Ábelová, M. (2005b): Analýza mikroštruktúr zubného cementu medveďov (*Ursidae*) z lokality jeskyně Za Hájovnou. – Geologické výzkumy na Moravě a ve Slezsku v roce 2004, 2-4, Brno.

Ábelová, M. (2007): Paleoclimate inferred from *Ursus spelaeus* teeth: the evidence from oxygen isotopes. – Scripta Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis, Geology, 35, 13th International Cave Bear Symposium, September 20 – 24, 2007, pp. 117-122.

Ábelová, M. (2008): Zánik ekosystému pleistocénneho a vznik eskosystému holocénneho. – Doctoral Thesis. Prírodovedecká fakulta, Masarykova univerzita, Brno, 189 s.

Absolon, K. (1905-1911): Moravský kras a jeho podzemní svět. I. 218 s.

D'Angela, D., Longinelli, A. (1990): Oxygen isotopes in living mammals' bone phosphate: further results. – Chem. Geol. (Isot. Geosci. Sect.), 86: 75-82.

Ayliffe, L. K., Lister, A. M., Chivas, A. R. (1992): The preservation of glacial–interglacial climatic signatures in the oxygen isotopes of elephant skeletal phosphate. – Palaeogeography, Palaeoclimatology, Palaeoecology, 99: 179-191.

Ayliffe, L. K., Chivas, A. R., Leakey, M. G.. (1994): The re tention of primary oxygen isotope compo sitions of fossil elephant skeletal phosphate. – Geochimica et Cosmochimica Acta, 58: 5291-5298.

Bouchud, J. (1966): Essai sur le Renne et la Climatologie du Paleolithique Moyen et Superieur. Perigeux: Imprimerie Magne.

Bocherens, H. (1991): Biogéochimie isotopique (13C, 15N, 18O) et paléoécologie des ours Pléistocènes de la Grotte D´Aldène. – Bulletin Musée Anthropologie Préhistorique Monaco 31: 29-49.

Bocherens, H. (2000): Preservation of Isotopic Signals (13C, 15N) in Pleistocene Mammals. – In: S. Ambrose – A. Katzenberg (Eds.): Biogeochemical Approaches to Paleodietary Analysis. Chapter 4, 21–24. Kluwer Academic/Plenum Publishers New York. 269 p.

Bocherens, H., Fizet, M., Mariotti, A. (1994): Diet, physiology and ecology of fossil mammals as inferred from stable carbon and nitrogen isotope biogeochemistry: implications for Pleistocene bears. – Palaeogegraphy, Palaeoclimatology, Palaeoecology 107: 213-225.

Bocherens, H., Fogel, M. L., Tuross, N., Zeder, M. (1995): Trophic structure and climatic information from signatures in a Pleistocene cave fauna of southern England. – Journal of Archeological Science, 22: 237-340.

Bocherens, H., Pacaud, G.., Lazarev, P. A., Mariotti, A. (1996): Stable isotope abundances (13C, 15N) in collagen and soft tissues from Pleistocene mammals from Yakutia: implications for the plaeobiology of the mammoth steppe. – Palaeogeography, Palaeoclimatology, Palaeoecology, 126: 31-44.

Bocherens, H., Stiller, M., Hobson, K. A., Pacher, M., Rabeder, G., Burns, J. A., Tütken, T., Hofreiter M. (2011): Niche partitioning between two sympatric genetically distinct cave bears (*Ursus spelaeus* and *Ursus ingressus*) and brown bear (*Ursus arctos*) from Austria: Isotopic evidence from fossil bones, Quaternary International, in press.

Bryant, J. D., Luz, B., Froelich, P. N. (1994): Oxygen isotope composition of fossil horse tooth phosphate as a record of continental paleoclimate. – Palaeogeography, Palaeoclimatology, Palaeoecology, 107: 303-316.

Bryant, J. D., Froelich, P. N., Showers, W. J., Genna, B. J. (1996): Biologic and climatic signals in the oxygen isotopic composition of Eocene–Oligocene equid enamel phosphate. – Palaeogeography, Palaeoclimatology, Palaeoecology, 126: 75-89.

Cerling, T. E., Harris, J. M. (1999): Carbon isotope fractionation between diet and bioapatite in ungulate mammals and implications for cological and paleoecological studies. – Oecologia, 120: 347-363.

CHKO Moravský kras (2009): http://www.moravskykras.ochranaprirody.cz/index.php?cmd=page&id=1213

Curci, A., Tagliacozzo, A. (2000): Determinazione dell´eta di morte e della stagione di cattura attraverso lo studio dei livelli di accrescimento di cemento e dentina nei denti di mammiferi: l´esempio di Riparo Dalmeri (TN). – Act of the 2 Covegno Nazionale di Archeozoologia, Asti 1997, pp. 23-30, Forli.

Dansgaard, W. (1964): Stable isotopes in precipitation. – Tellus, 16: 436-468.

Driessens, F. C. M., Verbeeck, R. M. H. (1990): Biominerals, pp. 85–97. CRC Press, Boca Raton, Florida.

Ehleringer, J. R., Cerling, T. E. (2002): Stable Isotopes. – In: H.A. Mooney, J.G. Canadell (eds.): Encyclopedia of Global Environmental Change, Vol. 2. The Earth system: Biological and ecological dimensions of global environmental change, Wiley: Chichester, pp. 544-550.

Enloe, J. G. (1993): Subsistence organization in the early Upper Paleolithic: Reindeer hunters of the Abri du Flageolet. – In: H. Knecht, A. Pike-Tay and R. White (eds.), Before Lascaux: The Complex Record of the Early Upper Paleolithic, CRC Press, Boca Raton. pp. 101-115.

Enloe, J. G., David, F. (1997): Rangifer herd behavior: seasonality of hunting in the Magdalenian of the Paris Basin. – In: L.J. Jackson and P. Thacker, (eds.), Caribou and Reindeer Hunters of the Northern Hemisphere. Avebury Press, Aldershot, pp. 47-63.

Enloe, J. G., Turner, E. (2004): Methodological problems and biases in age determinations: a view from the Magdalenian. – In: D. Ruscillo, (ed.), Ageing and Sexing in Zooarchaeology: Proceedings of the International Council for ArchaeoZoology, 2002. Oxbow Press, Oxford. pp. 129-144.

Feranec, R. S. (2004): Geographic variations in the diet of hypsodont herbivores from the Rancholabrean of Florida. – Palaeogeography, Palaeoclimatology, Palaeoecology, 207: 359-369.

Galiová, M., Kaiser, J., Fortes, F. J., Novotný, K., Malina, R., Prokeš, L., Hrdlička, A., Vaculovič, T., Nývltová Fišáková, M., Svoboda, J., Kanický, V., Laserna J. J. (2010): Multielemental analysis of prehistoric animal by laser-induced breakdown spectroscopy and laser ablation inductively coupled plasma mass spektrometry. – Applied Optics, 49: 191-199.

Geist, V., Baskin, L. (1990): Reindeer (Genus *Rangifer*). – In: Parker, S. P. (ed): Grzimek's Encyclopedia of Mammals. New York, McGraw-Hill, pp. 242-257.

Huertas, A., Iacumin, P., Stenni, B., Sanchez Chillón, B., Longinelli, A. (1995): Oxygen isotope variations of phosphate in mammalian bone and tooth enamel. – Geochimica et Cosmochimica Acta, 59: 4299-4305.

Hufthammer, A. K. (1995): Age determination of reindeer. – Archaeozoologia, 7/2: 33-42.

Iacumin, P., Bocherens, H., Mariotti, A., Longinelli, A. (1996): Oxygen isotope analyses of co-existing carbonate and phosphate in biogenic apatite: a way to monitor diagenetic alteration of bone phosphate? – Earth and Planetary Science Letters, 142: 1-6.

Iacumin, P., Nikolaev, V., Ramigni, M. (2000): C and N stable isotope measurements on Eurasian fossil mammals, 40 000 to 10 000 years BP: Herbivore physiologies and palaeoenvironmental reconstruction. – Palaeogeography, Palaeoclimatology, Palaeoecology, 163: 33-47.

Janis, C. M. (1984): The use of fossil ungulate communities as indicators of climate and environment. – In: Brenchley, P. (ed.): Fossils and Climate. Wiley, New York, pp. 85–104.

Janis, C. M. (1990): Correlation of cranial and dental variables with dietary preferences in mammals: a comparison of macropodoids and ungulates. – Memoirs of the Queensland Museum, 28: 349-366.

Janis, C. M., Damuth, J. D., Theodor, J. M. (2000): Miocene ungulates and terrestrial primary productivity: where have all the browsers gone? – Proceedings of the National Academy of Science, 97: 7899-7904.

Kay, R. F. (1975): The functional adaptations of primate molar teeth. – American Journal of Physical Anthropology, 43: 195-216.

Knies, J. (1900): Pravěké nálezy jeskynní Balcarovy skály u Ostrova na vysočině Drahanské. – Věstník Klubu přírodovědeckého v Prostějově za rok 1900, 3: 31-81.

Knies, J. (1902): Druhá zpráva o pravěkých nálezech v Balcarově skále u Ostrova. – Věstník Klubu přírodovědeckého v Prostějově za rok 1901, 4: 126-127.

Knies, J. (1928): První stopy lidské na Moravě. Sborník Přírodovědecké společnosti v Moravské Ostravě (1926–1928), 4: 45-80.

Koch, P. L., Fogel, M. L., Tuross, N. (1994): Tracing the diets of fossil animals using stable isotopes. – In: Stable Isotopes in Ecology and Environmental Science. Oxford, Blackwell Scientific Publications, pp. 63-92.

Koch, P., Tuross, N., Fogel, M. (1997): The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. – Journal of Archaeological Science, 24: 417-429.

Kufel, B. (2010): Use-wear analysis of magdalenian burins from Balcarka cave. – In: Z. Nerudová (ed.): Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 96-99. Brno.

Lee-Thorp, J. A., Van der Merwe, N. J. (1987): Carbon isotope analysis of fossil bone apatite. – South African Journal of Science, 83: 712-715.

Lee-Thorp, J., Sponheimer, M. (2003): Three case studies used to reassess the reliability of fossil bone and enamel isotope signals for paleodietary studies. – Journal of Anthropological Archaeology, 22: 208-216.

Longinelli, A. (1984): Oxygen isotopes in mammal bone phosphate: A new tool for paleohydrological and paleoclimatological research? – Geochimica et Cosmochimica Acta, 48: 385-390.

Luz, B., Kolodny, Y., Horowitz, M. (1984): Fractionation of oxygen isotopes between mammalian bone-hosphate and environmental drinking water. – Geochimica et Cosmochimica Acta, 48: 1689-1693.

MacFadden, B. J., Solounias, N., Cerling, T. E. (1999): Ancient diets, ecology, and extinction of 5-million-year-old horses from Florida. – Science, 283: 824-827.

McCrea, J. M. (1950): On the isotopic chemistry of carbonates and a paleotemperature scale. Journal of Chemical Physics, 18: 849-857.

Miller, F. L. (1974): Biology of the Kaminuriak population of barrenground caribou, Part 2. Canadian Wildlife Service Report Series 31.

Moravcová (Ábelová), M., Sabol, M. (2009): Attempt on the reconstruction of palaeotemperature and palaeoenvironment in the territory of Slovakia during the Last Glacial based on oxygen and carbon isotopes from tooth enamel and bone collagen of cave bears. – Acta Carsologica Slovaca, 47: 1, 5-18.

Moravcová (Ábelová), M.. (2010): Palaeoecological and palaeoclimatological interpretations on the base of isotope analyses 18O/16O and 13C/12C of *Rangifer tarandus*, *Equus* sp. a *Ursus* sp. enamel from Balcarka Cave (Moravian Karst, Czech Republic). – In: Z. Nerudová (ed.), Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 160-172. Brno.

Neruda, P. (2010): Chronologická pozice paleolitického osídlení jeskyně Balcarky ve středoevropském kontextu. – In: Z. Nerudová (ed.), Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 83-95. Brno.

Nerudová, Z., Neruda, P. (2010): Technologický a typologický rozbor kamenné štípané industrie z jeskyně Balcarky. – In: Z. Nerudová (ed.), Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 67-82. Brno.

Nývltová Fišáková, M. (2007): Sezonalita gravettských lokalit na základě studia mikrostruktur zubního cementu savců. – Přehledy výzkumů, 48: 13-23.

Nývltová Fišáková, M. (2008): Seasonality, palaeoecology and migration of fauna from the Gravettian sites. Abstract Book, pp. 63-64, Warszawa.

Nývltová Fišáková, M., Galiová, M., Kaiser, J., Fortes, F. J., Novotný, K., Malina, R., Prokeš, L., Hrdlička, A., Vaculovič, T., Laserna, J. J. (2009): Bear Diet, Seasonality and Migration Based on Chemical Multielemental Teeth Analysis. – Přehled výzkumů, 50: 27-34.

Palmquist, P., Gröcke, D.R., Arribas, A., Fariña, R. (2003): Paleoecological reconstruction of a lower Pleistocene large mammals community using biogeochemical (δ13C, δ15N, δ18O, Sr:Zn) and ecomorphological approaches. – Paleobiology, 29: 204-228.

Passey, B. H., Cerling, T. E., Perkins, M. E., Voorhies, M. R., Harris, J. M., Tucker, S. T. (2002): Environmental change in the Great Plains: an isotopic record from fossil horses. – Journal of Geology, 110: 123-140.

Pike-Tay, A., Morcomb, C. A., O'Farrell, M. (2000): Reconsidering the Quadratic Crown Height Method of Age Estimation for *Rangifer* from Archaeological Sites. – In: A. Pike-Tay (ed.), Assessing Season of Capture, Age and Sex of Archaeofaunas. ArchaeoZoologia monograph series, 11, pp. 145-174. La Pensee Sauvage, Paris.

Rašková Zelinková, M. (2010): Sobi z balcarky: sezonalita a demografie. – In: Z. Nerudová (ed.), Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 131-142. Brno.

Reinhard, E., Torres, T. de, O'Neil, J. (1996): $^{18}O/^{16}O$ ratios of cave bear tooth enamel: a record of climate variability during the Pleistocene. – Palaeogeography, Palaeoclimatology, Palaeoecology, 126: 45-59.

Richards, M. P., Hedges, R. E. M. (2003): Variations in bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of fauna from

Northwest Europe over last 40 000 year. – Palaeogeography, Palaeoclimatology, Palaeoecology, 193: 261-267.

Rozanski, K., Araguds-Araguds, L., Gonfiantini, R. (1992): Relation between long-term trends of 18O isotope composition of precipitation and climate. – Science, 258: 981-985.

Sánchez-Chillón B.S., Alberdi M.T., Leone G., Bonadonna F.P., Stenni B., Longinelli A. (1994): Oxygen isotopic composition of fossil equid tooth and bone phosphate; an archive of difficult interpretation. – Palaeogeography, Palaeoclimatology, Palaeoecology, 107: 317-328.

Seitl, L. (2010): Jeskyně Balcarka – zimoviště samic jeskynního medvěda. Osteologický materiál z výzkumu v roce 2007. – In: Z. Nerudová (ed.), Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 55-66. Brno.

Sillen, A. (1986): Biogenic and diagenetic Sr/Ca in Plio-Pleistocene fossils of the Omo Shungura Formation. – Paleobiology, 12: 311-323.

Sillen, A., Lee-Thorp, J. A. (1994): Trace element and isotopic aspects of predator–prey relationships in terrestrial foodwebs. – Palaeogeography, Palaeoclimatology, Palaeoecology, 107: 243-255.

Solounias, N., Teaford, M., Walker, A. (1988): Interpreting the diet of extinct ruminants: the case of a non-browsing giraffid. – Paleobiology, 14: 287-300.

Spiess, A. E. (1979). Reindeer and Caribou Hunters: An Archaeological Study. New York: Academic Press.

Valoch, K. (1960): Magdalénien na Moravě. Anthropos, 12 (N.S. 4). Brno.

Valoch, K. (1999): Příspěvek ke střednímu paleolitu jižní Moravy. – Acta Musei Moraviae – Scientiae socialis, 84: 3-7.

Valoch, K. (2001): Das Magdalénien in Mähren. 130 Jahre Forschung. Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz 48. Pp. 103-159, Mainz.

Valoch, K. (2010): Historie výzkumů jeskyně Balcarky. – In: Z. Nerudová (ed.): Jeskyně Balcarka v Moravském krasu. Interdisciplinární studie. Anthropos, 31 (N.S. 23), pp. 21-27. Brno.

Van der Merwe, N. J. (1982): Carbon isotopes, photosynthesis, and archaeology. – American Scientist, 70: 596-606.

Vrba, E. S. (1985): Ecological and adaptive changes associated with early hominid evolution. – In: Delson, E. (ed.), Ancestors: The Hard Evidence. Alan R. Liss, New York, pp. 63-71.

Walker, A., Hoeck, H. N., Perez, L. M. (1978): Microwear of mammalian teeth as an indicator of diet. – Science, 201: 908-910.

Wang, Y., Cerling, T. E., Quade, J., Bowman, J. R., Smith, G. A., Lindsay, E. H. (1993): Stable Isotopes of Paleosols and Fossil Teeth as Paleoecology and Paleoclimate Indicators: An Example from the St. David Formation. Climate Change in Continental Isotopic Records. Geophysical Monograph 78, Arizona, pp. 241-248.

Webb, S. D. (1983): The rise and fall of the late Miocene ungulate fauna in North America. – In: Nitecki, M.H. (ed.), Coevolution. University of Chicago Press, Chicago, pp. 267-306.

Zazzo, A., Le´cuyer, C., Mariotti, A. (2004): Experimentally-controlled carbon and oxygen isotope exchange between bioapatites and water under inorganic and microbially-mediated conditions. – Geochimica et Cosmochimica Acta, 68: 1-12.