RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Composition and provenance of raw material used for the production of Palaeolithic chipped stone industry in Nad Kačákem Cave (Bohemian Karst, Czech Republic)

Složení a provenience suroviny na výrobu paleolitické štípané industrie v jeskyni Nad Kačákem (Český kras)

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Nad Kačákem Cave, located in the Bohemian Karst (Czech Republic), has been investigated by archaeologists since the late 19th century. Archaeological finds are known only from a part of the cave, the Entrance Corridor. The oldest excavated archaeological horizon yielded a valuable collection of chipped stone industry. Published radiocarbon data indicate a calibrated radiocarbon age of c. 43–42.5 cal ka BP for this horizon. The assemblage is dominated by artefacts made of a dark grey to black fine-grained volcanic rock – andesite. A detailed petrographic comparison with volcanic rocks occurring within a 100 km radius from the cave identified two possible sources: Upper Cambrian andesite of the Křivoklát-Rokycany Volcanic Complex or, more probably, Upper Cambrian/lowermost Ordovician andesite of the Strašice Volcanic Complex. Lithics were knapped from pebbles rounded by transport in a stream. No suitable andesite pebbles were found in streams and fluvial sediments in the near vicinity of the cave. Nevertheless, they are abundant in streams within 20–30 km of the cave. This indicates that the cave dwellers were able to select suitable andesite pebbles at such a distance.

Middle/Upper Palaeolithic transition – cave – chipped stone industry – lithic provenance – Bohemian Karst

Jeskyně Nad Kačákem, nacházející se v Českém krasu, je archeologicky zkoumána již od konce 19. století. Archeologické nálezy jsou známy pouze z jedné části jeskyně, ze Vstupní chodby. Nejstarší odkrytý archeologický horizont poskytl cenný soubor štípané kamenné industrie. Publikovaná radiokarbonová data jej datují přibližně do období 43–42,5 tisíce let cal BP. V souboru převažují artefakty vyrobené z tmavě šedé až černé jemnozrnné vulkanické horniny, andezitu. Podrobné petrografické srovnání s vulkanickými horninami vyskytujícími se do vzdálenosti 100 km od jeskyně identifikovalo dva možné zdroje této suroviny: svrchnokambrické andezity křivoklátsko-rokycanského vulkanického komplexu, nebo spíše svrchnokambrické až nejspodněji ordovické andezity strašického vulkanického komplexu. Kamenné artefakty byly štípány z valounů zaoblených transportem ve vodním toku. Ve vodních tocích ani fluviálních sedimentech v bezprostředním okolí jeskyně nebyly vhodné andezitové valouny nalezeny. Hojně se však vyskytují ve vodních tocích vzdálených od jeskyně 20 až 30 km. To naznačuje, že obyvatelé jeskyně byli schopni vhodné andezitové valouny cíleně vybírat i v takové vzdálenosti.

přechod středního a mladého paleolitu – jeskyně – štípaná kamenná industrie – provenience kamenné suroviny – Český kras

Introduction

Early anatomically modern humans (AMH) were present in the Bohemian Karst near the transition of the Middle and Upper Palaeolithic, as confirmed by studies of the human skull from Koněprusy Cave (*Rmoutilová et al. 2018*; *Prüfer et al. 2021*; *cf. Mylopotamitaki et al. 2024*). This re-evaluation of an older find of human remains stimulated closer attention to

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other archaeological sites in the Bohemian Karst of approximately the same age. Any new review of available information and re-evaluation of the earlier finds represent important advances which can improve our understanding of human behaviour at this important transition – the gradual replacement of the earlier Neanderthal population by (and mixing with) AMH.

Nad Kačákem Cave (NKC) is located near Beroun-Hostim in Central Bohemia (Czech Republic) and represents an important Palaeolithic archaeological cave site. It provided evidence of a hearth, a collection of chipped stone industry (235 items) and rich finds of vertebrate macro-fauna and micro-fauna. The aims of this study of NKC are:

1. to determine the material composition of the major group of chipped stone industry from the cave and identify its probable source area;
2. to briefly discuss raw material types incorporated into the traditionally used local term 'chert of the Bohemian Karst type';
3. to discuss the history of the sedimentary filling of the Entrance Corridor of the cave.

Site description and earlier research

Cave location and description

NKC (WGS84 coordinates of the cave entrance: 49.9515°N, 14.1302°E, 249 m ASL) belongs to the Bohemian Karst, a small karst region that formed within Silurian and Devonian limestones in the southwestern part of Central Bohemia (*Žák et al. 2013*; *2016*). Reviews of cave archaeology of the area were presented by *Fridrich* and *Sklenář* (*1976*; Palaeolithic and Mesolithic) and *Sklenář* and *Matoušek* (*1994*; Neolithic to Middle Ages). The NKC entrance is located in a steep rocky slope 32 m above the left bank of the Loděnice (also Kačák) Stream, a tributary of the Berounka River, in an area strongly affected by 20th-century limestone quarrying. Owing to intensive speleological prospection and excavations of cave sediments deeper inside NKC by amateur speleologists (from the 1970s to the present), the total length of all NKC corridors is now 457 m with the altitude difference of 33 m.

Archaeological finds are known only from the Entrance Corridor (EC; names of cave parts were given, for example, by *Vlk et al. 2015*). This part of the cave is, at the level of the present-day sediment surface, 28 m long and max. 4.8 m wide. The EC is slightly inclined from the portal into the limestone massif, which is consistent with the direction of its filling by sediments from the outside.

Earlier archaeological research of NKC

Sedimentary fill of the EC contained several archaeological horizons – from below: a major horizon of late Middle or early Upper Palaeolithic age, followed by uncertain Magdalenian finds and by Neolithic, Eneolithic, Bronze Age, and Middle Age finds (*Zotz 1942*; *Petrbok 1944*; *Fridrich – Sklenář 1976*; *Fridrich 1982*; *Sklenář – Matoušek 1994*; *Ernestová 2006*). Most of the sediments, which originally filled the cave portal almost up to its roof (*Fig. 1*), were removed during several excavation campaigns. Excavations were started by J. Kafka before 1900, resumed by J. Petrbok between 1930 and 1935, L. F. Zotz



Fig. 1. Petrbok's excavations in the portal of Nad Kačákem Cave in the 1930s. The cave portal was originally filled with sediments almost up to its roof (photo by J. Petrbok, provided by B. Kučera).

in 1942, followed by minor research by F. Prošek and by several amateur excavations. Among these activities, the poorly documented excavations of amateur archaeologist J. Petrbok (*Petrbok 1940*; *1944*; *1956*) were by far of the largest volume. The research of L. F. Zotz focused on the sedimentary section left by Petrbok in the cave portal and was the only one with appropriate documentation (*Zotz 1942*). Archaeological finds from NKC are now kept in the collections of the Department of Archaeology of the National Museum in Prague, and the majority of vertebrate bones are kept in the collections of the Department of Paleontology of the National Museum in Prague. Unfortunately, both types of collections lack a detailed assignment of the finds to individual sediment layers of the EC.

The thicknesses of the individual sediment layers and their sedimentary character (colour and character of the soils, scree proportion, etc.) clearly varied in the direction from the cave entrance into deeper parts of the EC. Unfortunately, Petrbok published no longitudinal section of the EC sedimentary fill, and his cross-section sketch (*Petrbok 1944*) is only a schematic. More reliable documentation is represented by the short longitudinal section of the cave fill in the cave portal (*Fig. 2*) published by *Zotz* (*1942*; *1944*). Preservation of any remains of Last Glacial sedimentary fill with undisturbed stratigraphy in the EC is disputable, as the site was subjected to various amateur excavations in later times.

The age of the oldest and major archaeological horizon in the cave (base of layer 4 in *Fig. 2*) was disputed. *Petrbok* (*1940*; *1944*; *1956*) erroneously classified it in the Riss/Würm interglacial (Eemian in current terminology). In contrast, *Zotz* (*1942*) classified this horizon as an older part of the Last Glacial stratigraphy. Both of these authors speculated about a culture of cave bear hunters. Most of vertebrate bone finds occurred within or in the

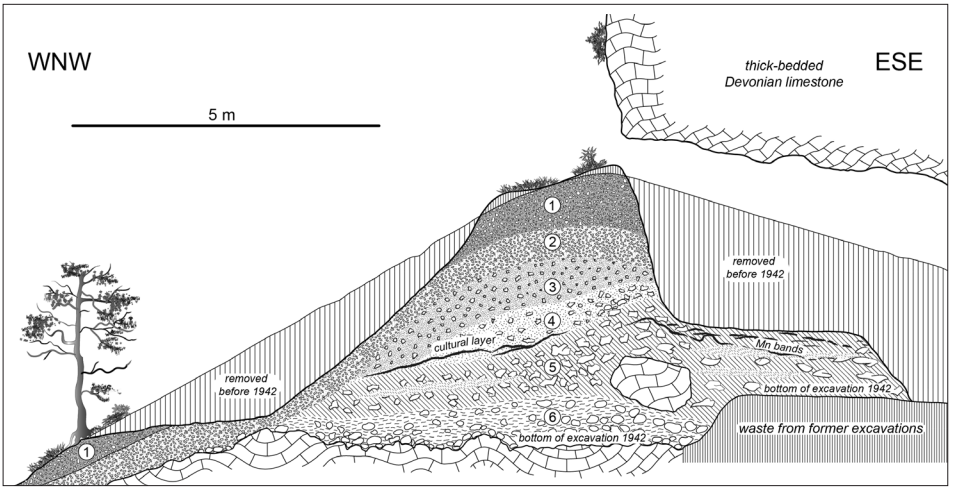


Fig. 2. Longitudinal section of sediments in the portal of NKC (redrawn after *Zotz 1942*, *1944*). Layer description was also modified and supplemented based on papers by *Petrbok* (*1940*; *1944*; *1956*) and our own observations: Layer K_1— angular limestone scree with black-brown humic soil in the matrix, finds of bones and teeth of Holocene fauna and fragments of pottery from the Middle Ages and deeper of Neolithic age; Layer K_2—light-coloured, pink to whitish, angular scree, no finds; Layer K_3— reddish to yellow soil with a minor content of angular limestone scree; a quartzite blade was found near the rock wall of the portal between layers K_2 and K_3; Layer K_4—yellow-brown loess-like soil with a very small share of limestone scree; individual limestone fragments with partly rounded edges. The studied cultural layer of the Middle/Upper Palaeolithic age was located at the bottom of layer K_4; it was grey to black, with many charcoal fragments, abundant chipped stone industry and animal bones (mostly bears); the cultural layer was well visible, and the same layers also contained red-burned stones from a hearth; Layer K_5—while the boundaries between layers K_1 to K_4 were less obvious (gradual transitions). The boundary between K_4 and K_5 was sharp; the upper surface of K_5 is represented by the trampled residence surface of Palaeolithic hunters, layer K_5 itself is represented by dark red-brown or dark yellow-brown soil with abundant large limestone fragments and scree, individual limestone fragments display rounded edges and are partly weathered; a horizon enriched in manganese was found on top of layer K_5 somewhat deeper in the EC. Layer K_6—the boundary between K_5 and K_6 was sharp again, layer K_6 is represented by green-white to blue-white clay interlayered with yellow-coloured bands; clay is plastic, with abundant limestone fragments having a weathered zone several centimetres thick on the surface; the transition to the weathered cave wall was gradual, the layer was without finds (sieving impossible due to the plastic character of the clay). K_6 is presumably of pre-Quaternary age.

proximity of the major Palaeolithic horizon. The classification of major vertebrate bones in the Last Glacial was confirmed by *Hokr* (*1949*; *1952*), who clearly documented that the vertebrate fauna is of glacial, not interglacial origin. He believed that it belongs to the beginning of Stadial W_2 in the old classical subdivision of the Last Glacial (i.e. c. 40–50 ka BP; *cf. Prošek – Ložek 1954*). Within a paper of wider scope, *Horáček* and *Sánchez Marco* (*1984*) studied vertebrate microfauna collected about 25 m inside the EC. They classified the finds to a wide time span (W_2, $W_{2/3}$, or W_3, i.e., c. 48–20 ka BP).

Diedrich and *Žák* (*2006*) revised the bones of vertebrate macrofauna from NKC (423 items) and reinterpreted the cave to be a frequented hyena den in the past. This conclusion was based on the presence of typically chewed bone fragments and remains of juvenile hyena bones. It should be mentioned that cave hyena disappeared from Central Europe around 40 ka BP (*Krajcarz et al. 2023*), which brings another age constraint to the EC

sedimentary fill. *Zotz* (*1942*) and *Petrbok* (*1944*) mentioned cave bear (*Ursus spelaeus*) bones present directly within the cultural layer. The decline of this species started in Europe around 40 ka BP (*Gretzinger et al. 2019*).

Previous studies of the raw materials of chipped stone industry

Petrbok (*1940*) classified the rock type used for the production of a majority of chipped stone industry of the oldest archaeological horizon as 'porphyrite'. This term, now invalid, denoted a volcanic rock of porphyritic texture usually containing plagioclase.

Zotz (*1942*) stated that the most widely used raw material for the artefacts was dark blue to grey silicified shale. *Skutil* (*1952*) and *Prošek* and *Ložek* (*1954*) followed Petrbok's determination of the rock. In contrast, *Fridrich* and *Sklenář* (*1976*) were closer to the opinion of *Zotz* (*1942*). *Ernestová* (*2006*) identified the dark-coloured rock as black quartzite. The local term 'chert of the Bohemian Karst type' was used for the description of the rock by some later authors (*e.g. Oliva 2016*). This term was frequently used by archaeologists for various types of fine-grained dark-coloured rocks used for the production of chipped stone industry in the Bohemian Karst area, usually without detailed petrographic determinations. In the last review, *Svoboda et al.* (*2025*) classified the major rock of the chipped stone industry as 'chert of the Bohemian Karst type' again.

Previous archaeological classifications of the chipped stone industry

Zotz (*1942*), working directly in the cave and familiar with the relationship of artefacts to the bones of Pleistocene vertebrate glacial macrofauna, classified the chipped stone industry as belonging to the Aurignacian. *Fridrich* (*1982*) re-evaluated the industry, considered the presence of Magdalenian as unprovable, and characterised the majority of the artefacts as Middle Palaeolithic, belonging to the early Last Glacial. He characterised it as Mousterian of the Levallois tradition, considering some significant phenomena, such as the rarely occurring narrow blades and knives as well as the loosening of the Middle Palaeolithic scheme of artefact processing, which indicates a relatively late stage in the development of this lithic tool tradition. In the case of several artefacts, he speculated about their affiliation to the Mauern-Ranis-Jerzmanowice technocomplex.

Based on a new evaluation of the stone industry, *Verpoorte* and *Šída* (*2009*) suggested that there was no Middle Palaeolithic present in NKC. They considered at least five long, fine regular blades to be of Upper Palaeolithic and probably Magdalenian age. This interpretation was followed by *Svoboda et al.* (*2025*), who speculated that the archaic appearance of the industry (which possibly can be all Magdalenian) could result from the poor quality of the raw material used. *Šída et al.* (*2025a*; *2025b*) suggested that the industry belongs to a late phase of Middle Palaeolithic or to an early phase of the Upper Palaeolithic.

Published radiocarbon data show that vertebrate macrofauna collected close to the main Palaeolithic archaeological horizon (base of layer K_4 in *Fig. 2*) has a radiocarbon age of c. 43 to 42.5 cal ka BP (*Verpoorte – Šída 2009*; the site was labelled Kačák Cave in this paper, and the conventional radiocarbon age for the older bone was 39 950±1000/750 BP). New radiocarbon dating in a similar range was mentioned by *Šída et al.* (*2025a*), which is in agreement with biostratigraphic classification, i.e. the presence of cave hyena and the dating of microfauna by *Horáček* and *Sánchez Marco* (*1984*).

This study is based on the assumption that the major Palaeolithic horizon corresponds to either a late phase of the Middle Palaeolithic or an early phase of the Upper Palaeolithic and that the collection of the artefacts from NKC possibly contains several admixed Magdalenian artefacts originating from a younger layer. We did not evaluate NKC artefacts made of other raw materials (pebbles of quartz, light-coloured quartzite, various types of sedimentary and diagenetic silicites, etc.). Instead, we focused on dominant volcanic rocks, which represent a clearly defined, uniform set in their composition and were produced by the Levallois technique of knapping.

We believe that our precise petrographic study of the dominantly used rock from the older archaeological horizon can, at least partly, dissipate the information mist around this important cave site.

Methods

Petrographic study of the stone artefacts and comparative rocks

Artefacts from the studied horizon of NKC, predominantly made of dark-coloured fine-grained volcanic rock (over 50% of artefacts) were first studied under an optical microscope. Their magnetic properties were determined by the KT-5 field kappa-meter (producer Geofyzika Brno, Czech Republic). The artefacts did not fill the measured volume of the kappa-meter completely, and the results are therefore only of indicative importance. Based on these methods, an artefact (item collection no. NM 72437) representing the most frequent rock type was selected for detailed analyses, including destructive methods. All analyses were conducted in the laboratories of the Institute of Geology of the Czech Academy of Sciences in Prague.

Bulk-rock X-ray diffraction (XRD) phase analyses were performed using a Bruker D8 Discover on both bulk pulverised rock and on separated magnetic minerals to get a better XRD record for the magnetic mineral fraction of the rock. Polished sections were studied using a standard petrographic microscope, and the chemical composition of individual rock-forming minerals was determined in the polished sections by a scanning electron microscope (SEM; Tescan VEGA 3XMU) equipped with an energy-dispersive X-ray spectrometer (EDS). Rock densities were determined by the usual method of double weighing in air and immersed in distilled water of a known temperature.

Methods of selection of comparative rocks

An important limit for the raw-material source of the chipped stone industry was the pebble mode of the used raw material. Part of a pebble surface is visible on more than one-half of the artefacts. The rock used must have been present in its source area in relatively high quantities to produce searchable pebbles in river terraces or active channels of the adjacent streams – the Berounka River and its tributaries. An arbitrary distance of 100 km (straight line, i.e. about three to four walking days) from NKC was selected. Such a distance was based on (1) the opinions of authors who studied the site earlier (see section 2), who all considered the sources of raw material as local; (2) the fact that the industry was produced from relatively large pebbles, which are difficult to transport from a distance

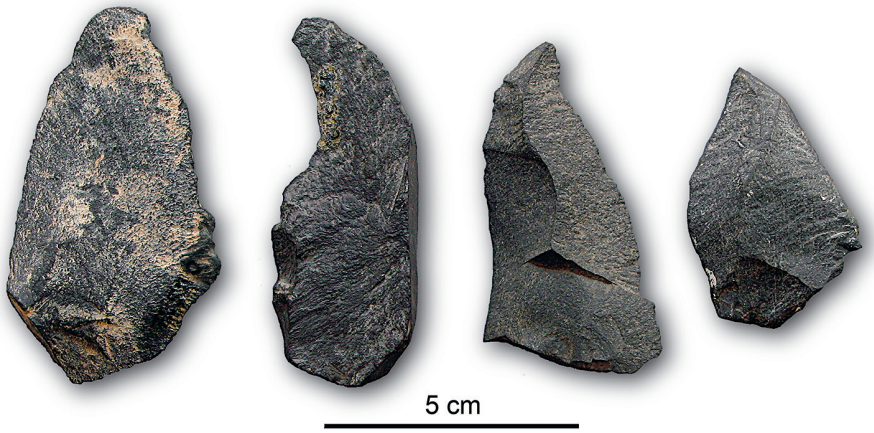


Fig. 3. Typical appearance of chipped stone industry from the major archaeological horizon of NKC. The second artefact has part of the pebble surface on its right side. National Museum in Prague, Archaeological Collection, from the left no.: H1-72520, H1-72512, H1-72511, H1-72518 (photo by K. Žák).

of several hundred kilometres; and (3) the technical feasibility of the research project – the number of field samples must not be too high, which would complicate the analytical processing.

Since the composition of the artefacts was already known, areas of rocks with a similar composition were selected based on published geological maps of the Czech Geological Survey. Outcrops of volcanic rocks in areas corresponding to the petrographic composition of artefacts were documented in the field and sampled. Rocks with fine crystallinity, appropriate magnetic properties, density and bulk appearance were studied by the same set of methods as the artefact. Full data for analytical procedures, descriptions of petrography and mineralogy of the comparative rocks, and of the chemical composition of their rock-forming minerals are presented in *Online Supplementary Material 1* (this material also contains a complete list of published literature related to the archaeological aspects of NKC).

Results

Artefact analysis

The study of the artefacts under an optical microscope and the measurement of their magnetic properties showed that more than 50% of the entire assemblage from NKC was derived from dark-coloured fine-grained volcanic rocks with elevated and frequently very high magnetic susceptibility. Sedimentary, diagenetic or hydrothermal quartzites can be excluded since they typically lack any magnetic signal.

Artefact no. NM 72437 represented an irregular flake, originally 39.5 mm in length, 40 mm in width and 16 mm in height. It revealed a part of the original pebble surface on one side and was made of fine-grained grey to black andesite. The typical appearance of chipped stone industry made from andesite from NKC (*Fig. 3*) and the appearance of the

Mineral phase	Average content in wt.%															
	n	F	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	V_2O_5	MnO	FeO	ZrO_2	HfO_2	Σ
Groundmass	4		0.08	0.66	1.00	96.37		0.10	0.58	0.16			1.05			100
Illite in groundmass	1		2.96	3.74	16.25	63.51		6.76	0.37	0.36			6.04			100
Plagioclase, lathy	12		4.86	0.15	28.43	54.33		0.43	10.75				1.05			100
Plagioclase, columnar	16		4.04		30.37	52.36		0.17	12.71				0.35			100
Plagioclase, columnar, outer zone	2		9.05		19.51	67.84		0.78	1.70				1.12			100
Amphibole	5		0.26	18.90	10.70	42.41		0.02	3.74	0.25			23.72			100
Amphibole chloritized	9			20.97	12.54	40.74		0.04	0.07				25.64			100
Pyroxene	5		0.19	14.87	1.93	51.29			15.72	1.13		0.15	14.72			100
Apatite	2	4.57				0.89	39.60		54.94							100
Ti magnetite	6			0.39	0.98	1.21			0.06	20.75	0.52	0.13	75.96			100
Magnetite	2			0.67	0.61	2.65			0.50	0.28			95.29			100
Ilmenite	6			0.44	0.17	1.02			0.17	52.05		1.58	44.57			100
Baddeleyite	1					0.86				2.22			1.56	93.83	1.53	100
Fe carbonate	2			20.07		0.34			52.40	0.51		2.70	23.98			100

Tab. 1. Chemical compositions of individual mineral phases of artefact NM 72437 based on EDS analyses. The compositions are averaged from the number of analysed points (*n*) and recalculated to 100%. Reliable analyses could not be obtained for a mixture of fine-grained mica and clay minerals present in the recrystallised glass.

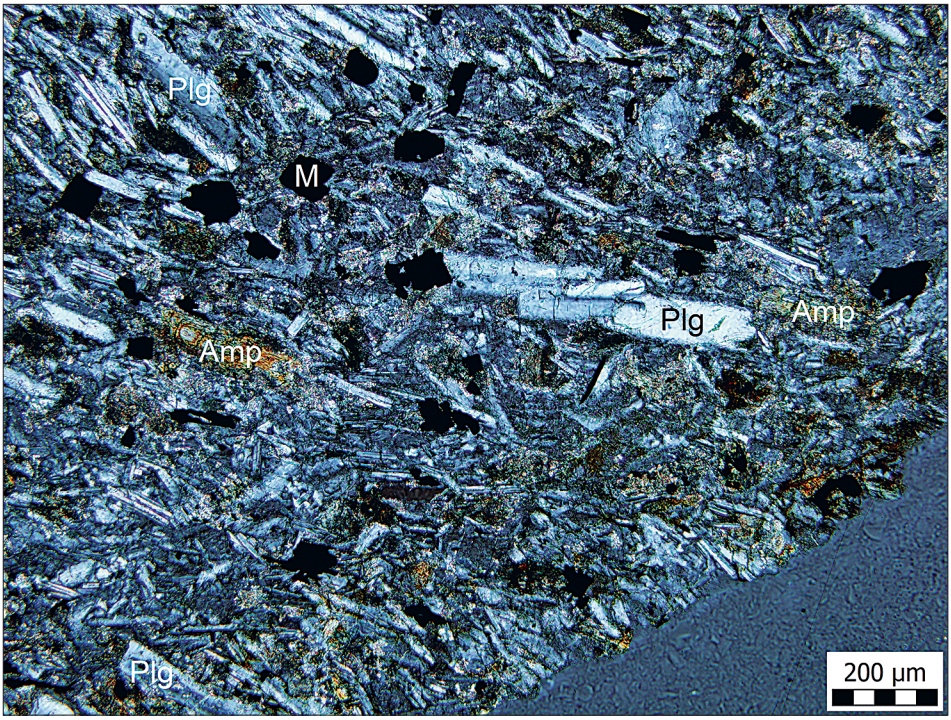


Fig. 4. A microphotograph of andesite of artefact NM 72437 in a petrographic microscope, transmitted light, crossed nicols. The fluidal texture of the rock is given by parallel arrangement of feldspars (plagioclase of andesine to labradorite composition). Amp—chloritized amphibole, M—magnetite, Plg—plagioclase (photo by J. Adamovič).

rock in polished section under a petrographic microscope (*Fig. 4*) well characterise the studied artefacts and the used volcanic rock.

Based on the microscopic study, the rock of artefact NM 72437 has a fluidal texture (*Fig. 4*). Its groundmass (about 10 vol.%) was originally formed by glass, later recrystallised to micro-crystalline mass of minerals with grain sizes below the resolution limit of optical microscopes (data from XRD analyses). The groundmass is herein called 'glass', even if recrystallised. The glass is silica-rich (*Tab. 1*) and represents an important component of the rock. The glass is responsible, together with the fine-grained nature of the rock, for its conchoidal fracture – a property valued by Palaeolithic hunters. Besides fine-grained microquartz, the groundmass also contains chlorite aggregates and clay minerals (illite based on elevated K_2O contents; *Tab. 1*).

Phenocrysts are dominated by plagioclases (80–85 vol.% of the rock), which occur in two populations of slightly different compositions (*Tab. 1*). Larger, columnar crystals show a rectangular cross-section, max. 160×600 µm in size, locally twinned. Smaller, lathy plagioclase crystals have typical dimensions 20×80 µm, and their longer axes show parallel alignment. Amphibole phenocrysts (max. 5 vol.% of the rock) are columnar, max. 100×300 µm in size, and their cleavage is blurred by chloritisation. Clinopyroxene of hedenbergite composition is present as an accessory. Opaque minerals, magnetite

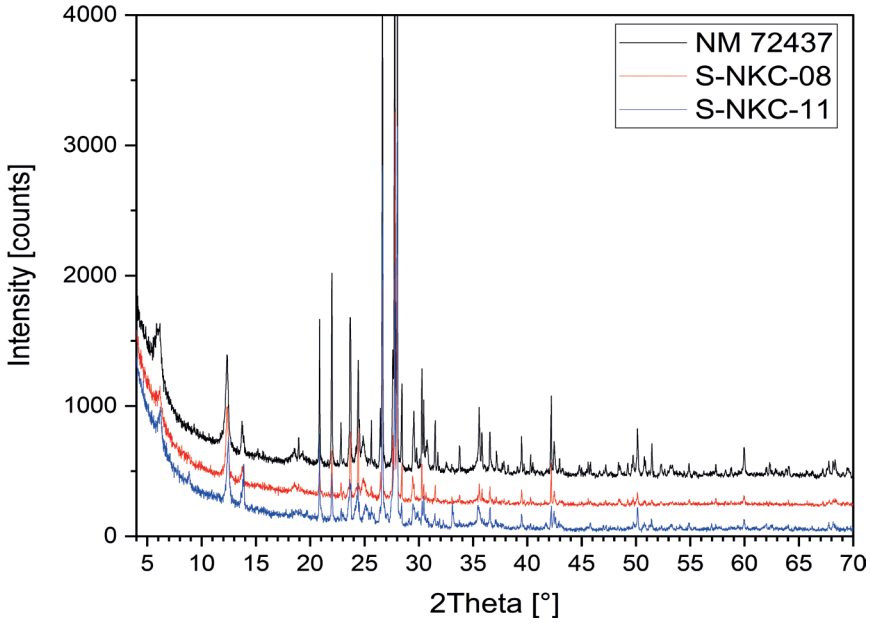


Fig. 5. Comparison of XRD pattern of artefact NM 72437 (black line) and XRD patterns of comparative rock samples S-NKC-08 (red line) and S-NKC-11 (blue line) (data by P. Mikysek).

and ilmenite, constitute together 5–8 vol.% of the rock, being responsible for its strong magnetic properties. Apatite was observed in a low quantity (max. 1 vol.%), and another accessory mineral is baddeleyite (ZrO_2). Anatase, indicated by XRD analyses, was not observed in the polished section. Rock densities of the artefacts produced from volcanic rocks range from 2.71 to 2.8 g/cm^3, and a great majority of them are strongly magnetic (they can hold a ferrite magnet).

Selection and analysis of comparative rocks

A total of 30 samples of comparative rocks (andesites, trachyandesites, basalts) were collected within a distance of 100 km from NKC. From this broad set, nine samples of rocks showing the best fit with the artefacts (i.e. having an andesite composition, fine-grained nature, and magnetic susceptibility similar to the artefacts) were subjected to detailed studies.

It should be noted that none of the compared rocks had parameters exactly identical to those of artefact NM 72437. In all cases, we found some differences in the presence of rock-forming minerals, their chemical composition, the size and arrangement of the phenocryst, the style and the degree of subsequent mineral alterations, and weathering (details of locations, geological position, petrography and other properties of all compared rocks are given in *Online Supplementary Material 1*). In general, the degree of alteration of the comparative rock samples was always higher than that of the rock of artefact NM 72437. Nevertheless, some of the comparative rocks showed very high degrees of compositional similarity with the artefact, as can be documented by similar bulk rock XRD patterns (*Fig. 5*).

Sample No.	Rock type	Location	WGS84 coordinates
S-NKC-08	andesite	Upper Cambrian of the Křivoklát-Rokycany Volcanic Complex, sampled from an outcrop near the ruins of Medieval Týřov Castle	49.97374°N 13.79120°E
S-NKC-09	andesite	Upper Cambrian of the Křivoklát-Rokycany Volcanic Complex, a pebble from the channel of the Oupoř Stream	49.97277°N 13.78778°E
S-NKC-11	andesite	Upper Cambrian to lowermost Ordovician of the Strašice Volcanic Complex, sampled in the Dolní Kvaň Quarry near Zaječov	49.76403°N 13.84531°E
S-NKC-29	andesite	Upper Cambrian to lowermost Ordovician of the Strašice Volcanic Complex, a pebble from the streambed of the Jalový Stream at the SW limits of Komárov	49.80375°N 13.85415°E
S-NKC-30	andesite to basalt	Upper Cambrian to lowermost Ordovician of the Strašice Volcanic Complex, a pebble from the channel of the Červený Stream at Hořovice	49.84030°N 13.90273°E

Tab. 2. Comparative rock samples showing the closest similarity to artefact NM 72437.

Comparative rocks showing the highest similarity to artefact NM 72437 with respect to their appearance under a petrographic microscope and in the chemistry of rock-forming minerals (*Tab. 2*) have their locations shown on a map (*Fig. 6*).

It should be noted that both identified source areas, the Křivoklát-Rokycany and Strašice volcanic complexes, are large volcanic regions with numerous types of volcanic rocks covering areas of many square kilometres. Even within a single andesite lava flow, there are differences in the degree of crystallinity, proportion of recrystallised glass, etc. The identification of a precise analogue to the artefact is therefore difficult. Our experimental chipping of the pebbles produced much better flakes with conchoidal fracturing and very sharp edges when using the rocks from the Strašice Volcanic Complex. Also, the Jalový and Červený streams draining this area with a mildly undulating landscape provided easier access from NKC and probably also better hunting conditions than the hillier area around the Berounka River. This region (*Fig. 6*) can therefore be considered the most probable source of pebbles used for the production of the chipped stone industry.

We also searched streambeds and older river terraces in the closer surroundings of NKC, i.e. of the Kačák Stream and Berounka River. Andesite artefacts from NKC have mostly strong magnetic properties, therefore a strong Nd-magnet was used to make the search more effective. Despite all efforts, not a single pebble of a similar rock was found. We are therefore confident that the used raw material comes from more distant sites.

Discussion

Major rock type used for the production of chipped stone industry of NKC

The chipped stone industry was predominantly produced from andesite pebbles rounded by stream transport. No appropriate andesite pebbles were found during our survey in the streams and fluvial sediments in the close surroundings of the cave. They are, however,

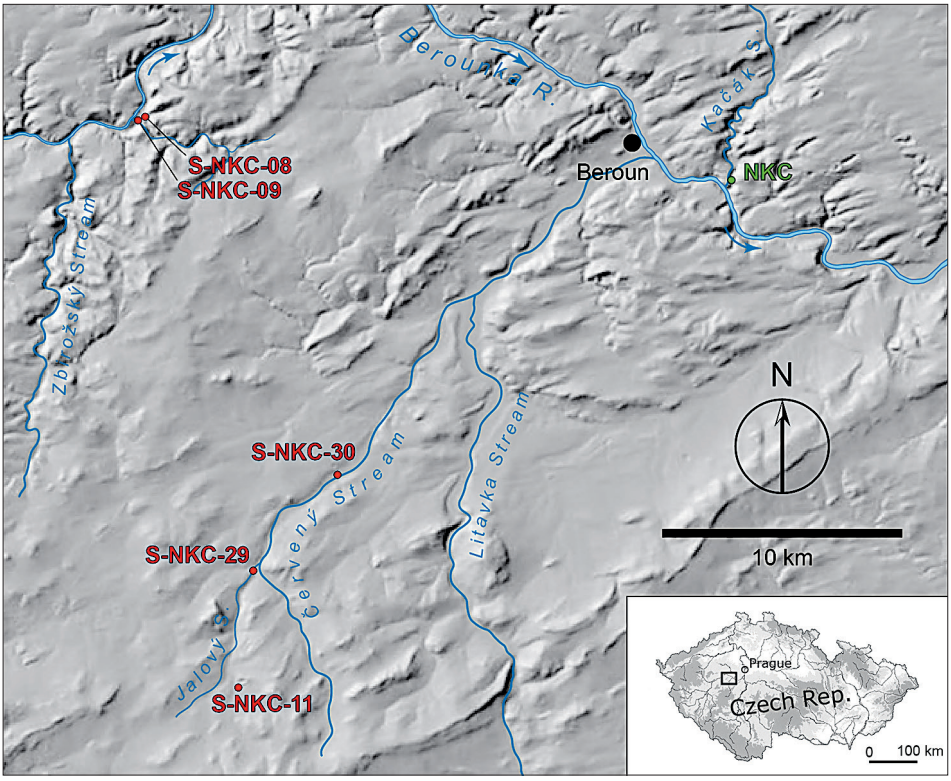


Fig. 6. A map with the locations of comparative rock samples most similar to the studied artefact NM 72437 in their properties. NKC—position of Nad Kačákem Cave (shaded relief by ČÚZK).

abundant in streams adjacent to the Křivoklát-Rokycany and Strašice volcanic complexes, about 20–30 km away. This indicates that NKC dwellers were able to select suitable pebbles of fine-grained andesite at these remote sites, possibly visited during hunting.

Similarly, *Šída et al.* (*2025*) described rocks used for the production of several stone artefacts accompanying the human bones of approximately the same age from Koněprusy Cave (also Bohemian Karst) as reflecting dominant rock sources within a few dozen kilometres of the cave. They classified the used rocks as ‘chert of the Bohemian Karst type’, a term discussed in detail in the following chapter. Note that the distance between NKC and Koněprusy Cave is only six kilometres.

Both cave sites with the proven presence of Palaeolithic hunters in the Bohemian Karst during the transition from the Middle to Upper Palaeolithic, i.e. Koněprusy Cave (*Rmoutilová et al. 2018*; *Prüfer et al. 2021*) and NKC, do not indicate any long-term stay by the hunters. More probably, they visited both sites only occasionally – the Koněprusy area for the burial of a woman and NKC for some likely shorter stays. The landscape of the Bohemian Karst (and also the Křivoklátsko area), with numerous rocky formations and steep slopes, possibly represented an environment less suitable for hunting. The more undulating landscape around the Jalový and Červený streams probably provided better hunting possibilities (cf. *Fig. 6*). The climatic conditions of Marine Isotope Stage (MIS) 3,

before the coldest and driest MIS 2 phase of the Last Glacial, probably enabled the migration of the hunters together with animal herds and the use of only temporary camps, which we are not able to identify today. In contrast, caves represent specific spatially-restricted contexts, where records of even occasional visits are easier to find.

The term 'chert of the Bohemian Karst type'

The precise petrographic determination of dark-coloured or black fine-grained opaque rocks requires, at a minimum, the manufacture of petrographic thin/polished sections and their microscopic study. This procedure is usually impossible in the case of rare archaeological artefacts, since it leads to their partial destruction. Some types of silicites that are partly translucent enable the determination of the rock type non-destructively, using a microscope and observation of the artefacts when immersed in water (*Přichystal 2013*). Unfortunately, this is not the case with opaque black rocks.

Palaeolithic chipped stone industries found in the area of the Bohemian Karst and its surroundings could be theoretically produced from several classes of such black or dark-coloured fine-grained rocks: Neoproterozoic chert, Upper Cambrian andesite and other volcanic rocks, Silurian silicified shales, cherts forming nodules in several types of Devonian limestones of the area (see *Přichystal 2013* for details). Because of the difficulties with a precise determination of these fine-grained opaque raw materials, archaeological practice gradually developed the term 'chert of the Bohemian Karst type'. This term was incorrectly used in the past by various authors as a 'black box' that contained various rocks, including andesite artefacts from NKC. This incorrect practice should be abandoned. *Přichystal* (*2013*) recommended using the term 'chert of the Bohemian Karst type' exclusively for radiolarites of the Devonian Choteč Limestone. Our recommendation is (in the case of larger assemblages of artefacts) to select one of them and sacrifice it for destructive petrographic analyses. When this is impossible, non-destructive analyses of the bulk chemical composition using portable XRF analysers (pXRF) can help to separate silicites (cherts) from volcanic rocks (higher contents of FeO, MgO) and silicified shales (higher content of Al_2O_3).

A new interpretation of sedimentary filling of the NKC Entrance Corridor

The study of complete archive information and a revision of the preserved sediments in the cave also made it possible to propose a new interpretation for the sedimentary fill of the EC of NKC. The lowermost sedimentary layer of the EC (K_6 in *Fig. 2*) is represented by light-coloured clays containing deeply weathered limestone debris. Towards the cave interior, these sediments are locally interlayered with lenses of light-coloured to white quartz sand. A comparison of the heavy mineral assemblage (heavy minerals – minerals with densities above c. 2.9 g/cm^3) of these sediments with typical heavy mineral assemblages of the surface Paleogene to Neogene and Quaternary river terraces indicate that the basal sediments of the EC are of pre-Quaternary age (probably deposited near the Paleogene/Neogene transition; *Žák et al. 2001*; *2004*). The Neogene age of these sediments was, based on their petrographic character, supposed already by *Petrbok* (*1940*; *1944*; *1956*) and *Ložek* (*1963*). Coarse fluvial sediments have been never found in NKC; no gravels with rounded pebbles were observed inside the cave (except for rare quartzite pebbles brought

to the cave and modified by humans to primitive tools). Considering also the cave morphology, it can be supposed that the cavities were formed by corrosion in a fully flooded, phreatic karst zone. The waters were most probably derived from Paleogene or Neogene rivers (cf. *Teodoridis 2004*) whose channels were positioned several dozen metres above the cave (*Žák et al. 2013*; *2016*).

These pre-Quaternary sediments of the EC were immediately overlain by layer K_5. This layer was represented by dark red-brown or dark yellow-brown soil with abundant large limestone fragments and scree, where individual limestone fragments displayed rounded edges and were partly weathered. Layer K_5 of a low thickness was topped by an Mn-enriched horizon (*Fig. 2*; see also *Zotz 1942*; *cf. Petrbok 1940*; *1944*; *1956*; *Ložek 1963*), presumably pre-Last Glacial in age. In a sharp contrast, the top of K_5 was overlain in the portal by a sedimentary complex of the Last Glacial and Holocene (K_4 to K_1), several metres thick and containing all of the cultural layers of the cave.

A great majority of pre-Quaternary and Early Quaternary caves in the Bohemian Karst, now hydrologically inactive, are largely filled with clastic sediments (*Žák et al. 2016*). It is therefore surprising that the EC of NKC, a large-sized corridor, slightly inclined towards the limestone massif and with a widely open cave portal, remained almost unfilled until the beginning of the Last Glacial. This is even more surprising when considering the altitude position of the cave portal relative to the dated system of river terraces (*Tyráček 2001*; *Tyráček et al. 2004*). The elevation of the cave portal corresponds to Middle Pleistocene river terraces dated approximately to 300–400 ka BP. At that time, the Kačák Stream was flowing very close to the cave (*Fig. 7*). Therefore, it remains to be explained why the EC was not completely filled with fluvial sediments of the Kačák Stream during the Middle Pleistocene.

We interpret the observed break in the sedimentary record of the EC as a result of a sudden opening of an older, almost empty fossil cave corridor by slope mass wasting processes. In general, phreatic cave corridors frequently change their directions – they are of a stochastic nature (*Ford – Williams 2007*). The continuation of the EC to the forefront of the present cave portal was probably bent upwards or sideways, or came to a dead end. This course could be related to the presence of a fault zone in front of the cave portal, which contains deeply weathered limestone (cf. *Ložek 1963*; *Kovanda 1965*). As the Kačák Stream valley deepened, it became widened by rock collapses and other slope mass wasting. These processes opened the entrance of an earlier existing cave corridor, forming a well-visible portal followed by a large, empty cave corridor. After this sudden mass wasting event, the cave started to attract both the humans and large cave-dwelling carnivores. The event must have occurred prior to the beginning of the Last Glacial, but not much earlier. An earlier opening would result in the deposition of larger volumes of sediments from the pre-Last Glacial periods inside the cave portal.

The presented interpretation of the evolution of the EC of NKC explains why the EC looked similar to its present appearance when the first human cave dwellers arrived at about 43–42.5 cal ka PB. Unfortunately, the poor field documentation by J. Petrbok prevents a deeper understanding of the relationship between the first human attendance in the cave and the existence of the cave hyena den. The hyena den must have been active before the first human presence, or shortly thereafter. Similarly, we do not know what share of the abundant macrofauna bones originate in predator prey and bones imported by humans. While traces of intentional human activity on the bones are extremely scarce (if any), traces

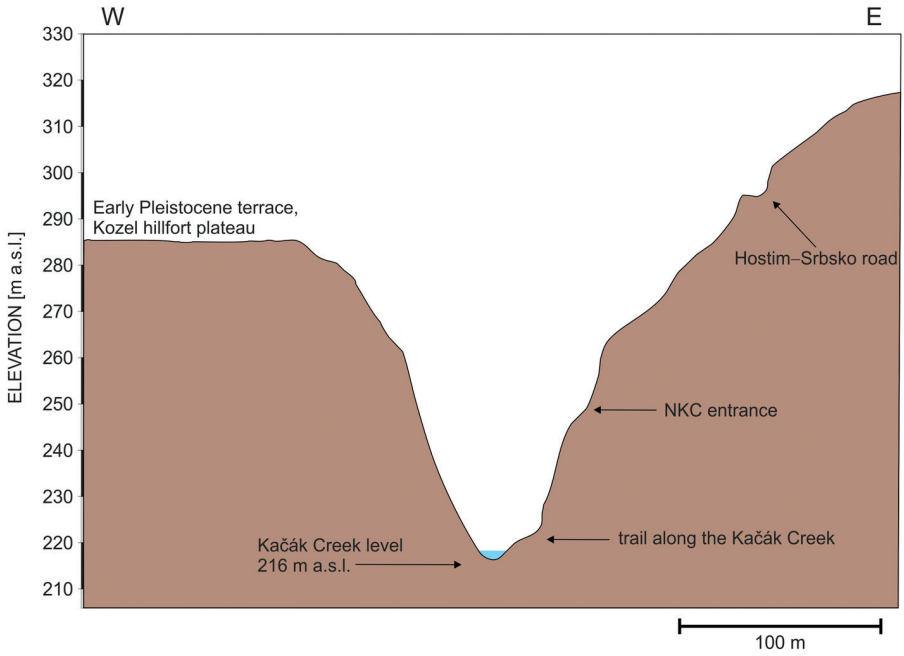


Fig. 7. A cross-section of the Kačák Stream valley with the position of the NKC portal. Altitude magnified 2.25× (elevation data by Digital Terrain Model of the Czech Republic of the 5th generation by ČÚZK).

of hyena activity are abundant (*Businský 1941*; *Diedrich – Žák 2006*). The exact relationship between the bear bones and the human presence in the cave will remain unsolved, too. *Zotz* (*1942*) and *Petrbok* (*1944*) found bear bones directly in the studied archaeological horizon.

Petrbok (*1940*; *1944*; *1956*) supposed the existence of a second, younger, Magdalenian cultural horizon, situated slightly deeper inside the EC than the major accumulation of chipped stone industry of the herein studied Middle/Upper Palaeolithic cultural layer. According to Petrbok, this supposed Magdalenian site is evidenced only by intentional traces on animal bones but lacks any support in stone artefacts. *Zotz* (*1942*) reported the find of an isolated quartzite blade between layers K_2 and K_3. Unfortunately, no more data exist to either support or disprove the presence of Magdalenian hunters in the EC of NKC. A modern evaluation of several long and narrow blades made of silicites, also present in the collected material, can possibly help solve this enigma in the future.

It is clear that the thickness of individual sedimentary layers was rapidly decreasing from the portal towards deeper parts of the EC. This is also supposed by the schematic unpublished interpretative longitudinal section of the EC drawn by F. Prošek in 1944 (published by *Fridrich – Sklenář 1976*). With respect to the burrowing activities of hyenas during the Last Glacial and of badgers during the Holocene, the original stratigraphy could have been disturbed in the more interior portions of the EC where the thicknesses of all layers were reduced. After the beginning of the Holocene, the filling of the cave portal by slope sediments derived from outside the cave continued with even higher intensity than during the Last Glacial (cf. *Fig. 2*).

Conclusion

Available biostratigraphic and published radiocarbon data indicate that the major archaeological horizon of Nad Kačákem Cave in the Bohemian Karst corresponds to a period of 43 to 42.5 cal ka PB (*Verpoorte – Šída 2009*; *Šída et al. 2025a*; *2025b*). A major part of the chipped stone industry was produced from a black to dark-grey fine-grained volcanic rock – andesite. The most probable source of the pebbles used for the production of the chipped stone industry are the Jalový Stream and Červený Stream watersheds, c. 20–30 km distant from the cave. Andesite of this area belongs to the Upper Cambrian – lowermost Ordovician Strašice Volcanic Complex. A minor part of the chipped stone industry for Nad Kačákem Cave was produced from other raw materials; it also shows a partly different typology and was not evaluated in this study.

The more undulating landscape around the Jalový and Červený streams probably provided better hunting conditions than the areas of the Bohemian Karst and Křivoklátsko. The variable but relatively warmer climatic conditions of MIS 3, before the coldest and driest MIS 2 phase of the Last Glacial, probably enabled migration of the hunters together with animal herds and use of only temporary camps. Any traces of the presence of Palaeolithic hunters are much more difficult to find on flat landscapes than in caves. Based on the performed lithics provenance study, we consider the presence of the hunters in the area of Jalový and Červený streams at the transition of the Middle and Upper Palaeolithic as proven.

In the past, numerous authors classified the fine-grained black or dark-coloured rocks used for the production of chipped stone industry in the Bohemian Karst area as 'chert of the Bohemian Karst type', bringing together Upper Cambrian andesite, Silurian silicified shale, and several types of cherts from nodules and layers in various types of Devonian limestones. To be determined precisely, these lithic artefacts call for a more detailed petrographic study.

A new interpretation of the filling of the Entrance Corridor of Nad Kačákem Cave supposes its formation in a phreatic regime during the Paleogene or Neogene and its sudden opening by slope mass wasting shortly before the beginning of the Last Glacial. The large, open corridor attracted both the humans and cave-dwelling animals and was rapidly filled by slope sediments from the outside and by cave roof frost shattering during the Last Glacial.

The study was supported by an internal research project of the Institute of Geology of the Czech Academy of Sciences within institutional support RVO67985831. The analyses are part of the ongoing project to identify rock sources used for the production of chipped stone industry in the Bohemian Karst. The project is focused on the pre-Neolithic collections of the National Museum in Prague (J. Eigner, K. Žák; for a complete record of the first part of the project, see Online Supplementary Material 1). SEM/EDS analyses for this study were kindly provided by N. Mészárosová of the Institute of Geology, Czech Academy of Sciences. Thanks to Jana Rajlichová of the same Institute for a precise redrawing of the original figure by L. F. Zotz and for drawing the location map. The authors also wish to thank M. Hejna for geodetic work. We appreciated reviews by S. Diemer and one anonymous reviewer, who helped us significantly improve the manuscript.

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Úplně aktuálně to ale vzhledem k bezpečnostnímu problému v PHP nefunguje.

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