Journal of Archaeological Science: Reports 38 (2021) 103014

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Chronostratigraphy of Jerzmanowician. New data from Koziarnia Cave, Poland

Małgorzata Kot [a,*], Maciej T. Krajcarz [b], Magdalena Moskal-del Hoyo [c], Natalia Gryczewska [a], Michał Wojenka [d], Katarzyna Pyżewicz [a], Virginie Sinet-Mathiot [e], Marcin Diakowski [f], Stanisław Fedorowicz [g], Michał Gąsiorowski [b], Adrian Marciszak [h], Grzegorz Lipecki [i], Paweł Mackiewicz [j]

[a] University of Warsaw, Faculty of Archaeology, Warsaw, Poland
[b] Institute of Geological Sciences, Polish Academy of Sciences, Warsaw, Poland
[c] W. Szafer Institute of Botany, Polish Academy of Sciences, Cracow, Poland
[d] Jagiellonian University, Institute of Archaeology, Cracow, Poland
[e] Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany
[f] University of Wrocław, Instutite of Archaeology, Wrocław, Poland
[g] University of Gdańsk, Department of Geomorphology and Quaternary Geology, Institute of Geography, Gdańsk, Poland
[h] University of Wrocław, Department of Palaeozoology, Institute of Environmental Biology, Faculty of Biological Sciences, Wrocław, Poland
[i] Institute of Systematics and Evolution of Animals, Polish Academy of Sciences, Cracow, Poland
[j] University of Wrocław, Department of Bioinformatics and Genomics, Faculty of Biotechnology, Wrocław, Poland

A R T I C L E I N F O

Keywords:
Cave site
Middle/Upper Palaeolithic transition
Leafpoint industries
Lincombian-Ranisian-Jerzmanowician
Early Gravettian

A B S T R A C T

Lincombian-Ranisian-Jerzmanowician (LRJ) industries are extremely scarce in Central Europe. Therefore, each LRJ site is of great importance. One of them is Koziarnia Cave in Poland situated eastwards relative to other LRJ sites. Our investigations of this cave provided new chronostratigraphic data for the LRJ industries. A detail debitage analysis recognised the ventral thinning chips and enabled identification of the LRJ assemblage-containing stratum. Besides the LRJ assemblage, strata with traces of Late Middle Palaeolithic and Early Gravettian occupation were found at the site. The radiocarbon dates of Koziarnia samples show that the archaeological settlement represents one of the oldest Gravettian stays north to the Carpathians. Moreover, these dates demonstrate that humans and cave bears had alternately occupied the cave. Additionally, the radiocarbon dates indicate relatively young chronology of the Jerzmanowician occupation in Koziarnia Cave (ca. 39-36 ky calBP). The results suggest the long chronology of the LRJ technocomplex, exceeding the Campanian Ignimbrite event.

1. Introduction

Middle/Upper Palaeolithic transitional industries in Central Europe are the most ephemeral and most debated topics in Palaeolithic discourse (Hublin and Bailey, 2006; Straus, 2009; White, 1982). After over 100 years of research, we are still seeking for answers to crucial questions regarding, e.g. the origins (Allsworth-Jones, 2004; Higham et al., 2009; Neruda and Nerudová, 2013; Tostevin, 2013; Villa et al., 2018), the chronology (Bobak et al., 2013; Jöris et al., 2011), internal divisions (Allsworth-Jones, 1986; Hublin, 2015; Svoboda, 2004), or even the identification of human populations responsible for these industries (Flas, 2011; Higham et al., 2011; Hoffecker, 2009; Valoch, 2000; Svoboda, 2001; Zilhão, 2013).

Lincombian-Ranisian-Jerzmanowician (LRJ) is one of such transitional industries determined by the presence of bifacially worked leaf-points made on blades obtained from double platform cores. Technological and experimental studies show that one deals with a predetermined technique of obtaining leaf-shaped blades, which were later minimally adjusted to reflect the exact willow leaf shape through ventral thinning. Such technological features are present in transitional assemblages in southern Poland (Nietoperzowa Cave), southern Germany (Ranis), Belgium (Spy) and the southern part of Great Britain

* Corresponding author.
E-mail address: m.kot@uw.edu.pl (M. Kot).

https://doi.org/10.1016/j.jasrep.2021.103014
Received 24 September 2020; Received in revised form 22 January 2021; Accepted 16 April 2021
Available online 3 May 2021

(Beedings, Kent's Cavern), but are relatively less abundant to the south of the Carpathians, where Szeletian industry prevails (Chmielewski, 1961; Flas, 2012; Hülle, 1939; Jacobi, 2007).

The term "Jerzmanowician" was used for the first time in 1961 by W. Chmielewski after his studies in Nietoperzowa Cave located in Jerzmanowice village (Chmielewski, 1961). Chmielewski's research focused on two caves, Koziarnia and Nietoperzowa, where the first bifacial leafpoints were found already in the 19th century. In the second half of the 19th century, the cave sediments of several sites were exploited by local landlords to be sold as field fertiliser. In consequence, the sediments of caves Nietoperzowa, Koziarnia and Gorenicka were heavily destroyed. During the cave sediment exploitation, multiple prehistoric animal bones and artefacts were found. The discoveries led Ferdinand Römer (1883); (1884;), a geologist and palaeontologist from Schlesische Friedrich-Wilhelms-Universität in Breslau, to study the cave sediment as well as palaeontological and archaeological assemblages in detail, including bifacial leafpoints from Nietoperzowa and Koziarnia caves. To check their stratigraphy, Chmielewski re-excavated both caves in the 1950s. In Nietoperzowa Cave, he found three archaeological horizons (layers 4, 5a and 6), containing in total >87 bifacially worked leafpoints and their fragments (Chmielewski, 1975). In Koziarnia Cave, Chmielewski opened ten trenches covering the area of 120 m^2 in total, but none of the identified 21 layers could be clearly described as containing the Jerzmanowician assemblage. One of the layers, i.e. 13, which he claimed did not contain any stone artefacts, was black due to the high amount of charcoal (Chmielewski et al., 1967). Chmielewski called it a "cultural layer", and by comparing it to layers 4 and 6 in Nietoperzowa Cave, he initially suggested that it was a Jerzmanowician horizon (Chmielewski, 1961). However, no radiometric dates were obtained at that time to test the hypothesis.

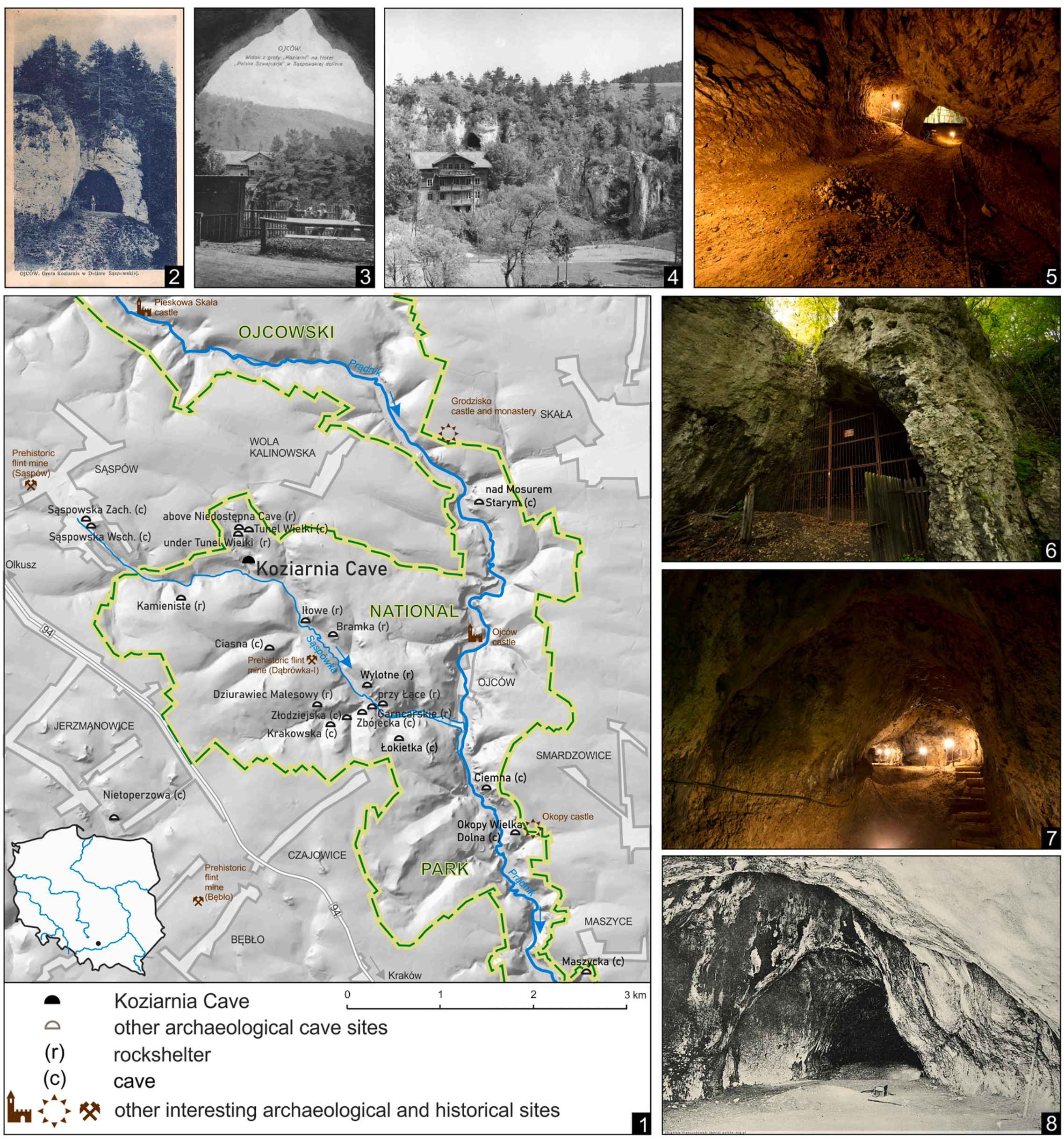

Fig. 1. Koziarnia Cave, its surroundings and state of preservation. (1) The localisation of Koziarnia Cave. (2) Postcard dated to 1927 illustrating the entrance to Koziarnia Cave. (3) 1st half of the XXth century, view from the Koziarnia Cave on the "Szwajcaria" hotel, situated on the opposite slope of Koziarnia Gorge. At that time a dance floor was built inside the cave. (4) Koziarnia Cave during excavations of prof. Chmielewski in 1958–1962 (photo from the archives of prof. T. Madeyska-Niklewska). (5-6) Koziarnia Cave during excavations in 2017. (7) The current state of preservation of Koziarnia cave sediment. The sediments inside the cave are partly destroyed by collapsed unfilled archaeological trenches and ditches made during the installation of the seismograph at the back of the cave. (8) State of preservation of Koziarnia Cave sediment in 1910. The pit visible in the middle part may be a remnant of the F. Römer fieldworks in 1879.

A single radiocarbon date (38,160 ± 1250 BP Gro-2181) obtained for wood charcoal from layer 6 in Nietoperzowa Cave was presented by Chmielewski (1961), and since then it has been treated as the major chronological framework of the whole technocomplex. It was later proposed that all the assemblages containing bifacially-worked blade leafpoints from the European Plains can be merged into one industry, i.e. Lincombian-Ranisian-Jerzmanowician, a term widely used till today (Desbrosse and Kozłowski, 1988). Even though the Jerzmanowician culture's determination was based mostly on the Nietoperzowa Cave assemblage, the Koziarnia and Mamutowa caves were also classified to LRJ.

The chronology of Jerzmanowician was restudied several times (Flas, 2011; Kozłowski and Kozłowski, 1996; Kozłowski, 2002; Lorenc, 2013; Nadachowski et al., 2011). The analyses were, in most cases conducted on the animal fossil collection. The most recent results of multiple radiocarbon dating of cave bear remains from Nietoperzowa Cave (Krajcarz et al., 2018) showed the old collection's limitation. The radiocarbon range of each stratum represents all chronological spectra observed in the cave, which might indicate problems resulting from the exploration, documentation or mixing of this collection. Only new detailed fieldwork would help to resolve all the chronological issues linked to LRJ industries.

In order to clarify the chronostratigraphic position of Jerzmanowician, a new fieldwork project was initiated in 2017. It aimed at the verification of the stratigraphy of Koziarnia Cave and obtaining reliable radiometric dates for a complete profile of the site, as well as reconstructing the palaeoenvironmental conditions for individual strata (Kot et al., 2019a). The paper presents the chronostratigraphic data with a comparison to the results published before.

1.1. Koziarnia cave

Koziarnia Cave is located in Sąspów Valley, in the southern part of the Polish Jura (Fig. 1). The cave has a 5-metre-high entrance heading SW with the main chamber covering an area of over 100 m^2 behind it and a single 40-metre-long gallery narrowing toward the cave's end.

The cave was constantly used until World War I. At the beginning of the 20th century, when the sediment exploitation was halted, a dance floor was built in the main chamber, and a resting place was located on the terrace in the front of the entrance. In 1919, the cave was excavated by S. Krukowski, who at the same time conducted fieldwork in the nearby Ciemna Cave (Kot et al., 2019b; Kozłowski, 2007). Krukowski made a trench in the entrance zone of the cave, finding nothing but some Holocene artefacts. In 1958–62, the cave was excavated again by W. Chmielewski. He found most of the sediments in the main chamber already destroyed due to the previous activities. Inside the cave, undisturbed layers were found as far as 20 m from the cave entrance. In his final publication, Chmielewski described the cross-section as having 21 separate geological layers (Chmielewski et al., 1967). Several of them contained flint artefacts. Originally, Chmielewski distinguished eight cultural layers (4, 7, 10, 13, 16B, 17, 18, 20), out of which layers 4, 7, 10 and 13 contained only charcoal and no lithic artefacts.

Lithic artefacts were found only in the lower layers. Middle Palaeolithic settlement was associated with layers 17, 18 and 20. The small assemblage contained two bifacial backed knives, several flake discoid cores and postdepositionally damaged debitage. Rare stone artefacts also described as Middle Palaeolithic were found in layers 15 and 16. One of the artefacts found in layer 15 (mistakenly published as coming from layer 17) is a massive blade made on a double platform core with multiple postdepositional retouches (Chmielewski et al., 1967). The archaeologically sterile layer 13 was described as black due to a high

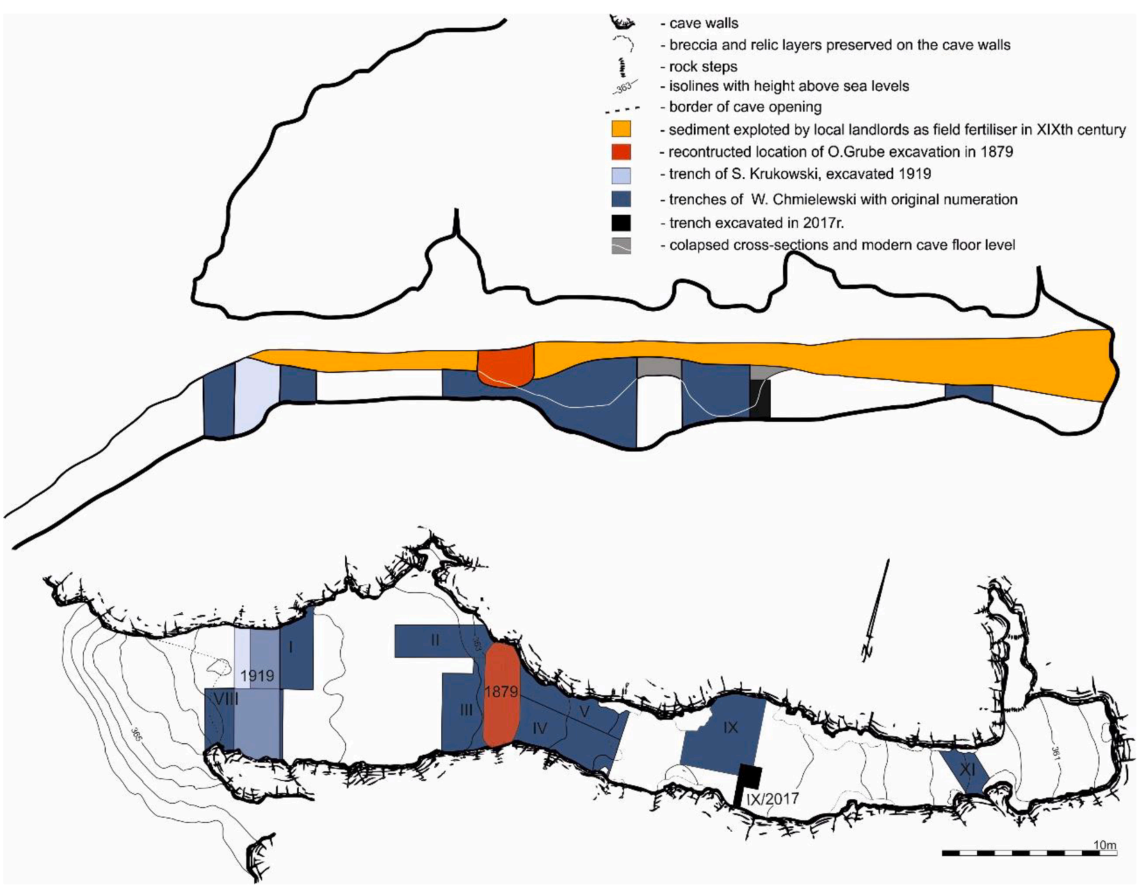

Fig. 2. Plan and cross-section of Koziarnia Cave with the localisation of all previous archaeological fieldworks.

charcoal concentration. The charcoal concentration was especially high in the main corridor (20–35 m from the entrance). The upper part of the section was minimally present only in the trenches located farther from the entrance. Chmielewski correlated them with the loess sequences found in the front of the cave and dated to MIS 2.

Unfortunately, the trenches were not refilled after the excavations, and they have stayed open for 70 years. All the walls disintegrated slowly causing massive damage (Fig. 1: 7).

2. Methods and materials

The new fieldwork conducted in 2017 covered 2.85 m^2 (Fig. 2). A trench was opened 40 m from the cave entrance in the NW corner of Chmielewski's trench IX to correlate the stratigraphy and open a section in the place that could cover the highest possibly undisturbed profile. The collapsed walls of the old trenches containing mixed sediment were visible during the fieldwork. One should still consider that even the stratified parts of the trench might be postdepositionally moved due to the slight trench wall movements. The geogenic sediment was excavated from natural layers divided into an artificial 10 cm spit. The sediment from one square metre of natural layer and artificial spit was collected separately. The collected geogenic sediment was wet sieved with 1 mm sieves and the mixed sediment with 3 mm sieves. The sieved material was dried and screened in order to collect tiny microfaunal, anthracological and archaeological material. All the *in situ* findings, including the charcoal, were 3D measured.

Additionally, the old collection of artefacts found in Koziarnia by F. Römer in 1879 was restudied. For chronostratigraphic studies, two unpublished ivory tools were radiocarbon dated and analysed in terms of traceology and zooarchaeology using mass spectrometry (ZooMS).

2.1. *Chronology*

2.1.1. *Radiocarbon dating*

Each charcoal fragment was taxonomically identified based on wood anatomy atlases (Greguss, 1955; Schweingruber, 1990) and the modern wood collections in the Department of Palaeobotany of the W. Szafer Institute of Botany of the Polish Academy of Sciences. Only the identified fragments were dated (Table 1). The selection of the most suitable charcoal fragments is based on woody flora typical of the environmental conditions for a specific period. If possible, remains of branches identified by an observation of a ring curvature is chosen, in order to avoid the old wood problem (Moskal-del Hoyo and Kozłowski, 2009; Nowak et al., 2017). For MIS 3, it is more adequate to select taxa representing coniferous wood more widespread in the Pleistocene cold conditions in Central Europe (Beresford-Jones et al., 2010; Cichocki et al., 2014; Svoboda et al., 2015; Alex et al., 2017; Wilczyński et al., 2020). When no charcoal fragments were available from a chosen stratum, animal fossils were used for dating. All cave bear remains were assigned to *Ursus ingressus* according to preliminary analyses of ancient DNA as well as previous studies, which indicated that only this species (not *U. spelaeus*) was present on the territory of Poland in the Pleistocene (Baca et al., 2012, 2014, 2016; Mackiewicz et al., 2017). Due to the proximity to the edge of the old trenches and possible contamination of the sediment, only samples collected in the deepest part from the old trench's edge were used.

Wood charcoal fragments, bones, teeth and ivory were dated with the AMS radiocarbon method. None of the dated bones nor teeth had cut marks or traces of human activities. Fifteen bone and 15 charcoal samples were dated in the Poznań Radiocarbon Laboratory (Poland), two bone tools were dated in the Oxford Radiocarbon Unit (UK) and two cave bear bones in the Gliwice Absolute Dating Methods Centre (Poland). In the case of bone, teeth and ivory artefacts, the dated fraction was collagen, and in the case of charcoal, it was cellulose. Collagen and cellulose extraction and purification in Poznań and Gliwice followed widely accepted methodology (Goslar et al., 2004; Brock and Higham,

Table 1
Radiocarbon dates from Koziarnia Cave.

date code	sample inv. No	dated material	species	trench	original layer	final layer	C14 date (uncalibrated)	C:N ratio in bone collagen	comments
OxA-39509	MMW/2661.4	bone tool	*Elephantidae*	?/1879	?	?	22020 ± 150 BP	–	
OxA-39539	MMW/2661.5	bone tool	*Elephantidae*	?/1879	?	?	20870 ± 210 BP	–	
Poz-82394	–	bone	*Ursus arctos priscus*	?/1879	?	?	39200 ± 1100BP	2.94	8.4% coll
Poz-119319	KOZ_IX_4_5	bone/mandible	*Ursus ingressus*	IX/1961	4/5	3–5	25440 ± 210 BP	3.08	
Poz-119320	KOZ_IV_2	bone/skull	*Ursus ingressus*	IV/1960	2a	9–11	27340 ± 260 BP	3.08	
GdA-3898	Koz-04–12	tooth/M2	*Ursus ingressus*	IX/1961	12?	10?	32440 ± 240 BP	3.5	
Poz-98895	C9	charcoal	*Picea abies/Larix decidua*	IX/2017	K	12	28090 ± 360 BP	–	0.3 mgC
Poz-98898	C52	charcoal	*Pinus* sp.	IX/2017	K'	13	30330 ± 500 BP	–	0.2 mgC
Poz-99773	B68	tooth/I	*Ursus ingressus*	IX/2017	D	15	37650 ± 900 BP	3.19	1.9% coll
Poz-99816	B254	tooth/M1	*Ursus ingressus*	IX/2017	D	15	39000 ± 1000 BP	3.17	4.0% coll
Poz-98425	C63	charcoal	*Pinus* type *sylvestris-mugo*	IX/2017	D	15	220 ± 30 BP	–	
Poz-98902	C99	charcoal	*Juniperus communis*	IX/2017	E	16a	145 ± 30 BP	–	
Poz-110657	C102	charcoal	*Pinus* type *sylvestris-mugo*	IX/2017	F	16b	33100 ± 1200 BP	–	0.14 mgC
Poz-99806	B125	bone/phalange	*Ursus ingressus*	IX/2017	F	16b	26160 ± 180 BP	too low collagen quantity	0.3% coll, 0.9 mgC
Poz-98896	C26	charcoal	*Picea abies/Larix decidua*	IX/2017	F	16b	29430 ± 720 BP	–	0.13 mgC; incorrectly carbonised
GdA-3896	Koz-01–7	tooth/i3	*Ursus ingressus*	IV/1960	7	15–16	39340 ± 430 BP	2.8	
Poz-98901	C101	charcoal	*Pinus* type *sylvestris-mugo*	IX/2017	H'- cleaning section	17	33230 ± 480 BP	–	0.8 mgC
Poz-99815	B165	tooth	*Ursus ingressus*	IX/2017	H'	17	40100 ± 1100 BP	3.17	4.3% coll
Poz-99814	B160	bone/metapodium	*Ursus ingressus*	IX/2017	H'	17	>45000 BP	3.19	4.5% coll
Poz-116687	B200	tooth	*Ursus ingressus*	IX/2017	I	17	40600 ± 1200 BP	3.13	
GdA-3897	Koz-02-10_10a	bone/metapodium	*Ursus ingressus*	V/1960	10-10a	19–20	24190 ± 120 BP	3.1	
Poz-98899	C56	charcoal	*Pinus* type *sylvestris-mugo*	IX/2017	L/M	19–21	140.23 ± 0.37 pMC		0.7 mgC
Poz-98900	C57	charcoal	*Pinus* type *sylvestris-mugo*	IX/2017	M	21	175 ± 30 BP		0.6 mgC

2010). Bones and teeth were rinsed with NaOH and subject to ultrafiltration (>30 kDa). For details of the chemical pre-treatment, target preparation and AMS measurement of samples dated in Oxford Radiocarbon Unit see Bronk Ramsey et al. (2004) and Brock and Higham (2010). The radiocarbon ages were calibrated versus the INTCAL'13 radiocarbon atmospheric calibration curve (Reimer et al., 2013), using the software OxCal ver. 4.3.2 (Bronk Ramsey, 2009, 2017; Bronk Ramsey et al., 2013). All calibrated dates are presented in calibrated years BP with 95.4% probability range.

2.1.2. Thermoluminescence dating

Additionally, the bottom-most layer of silty loams was thermoluminescence (TL) dating in the Department of Geomorphology and Quaternary Geology of the University of Gdańsk. The deposit moisture was measured in each sample. After drying, the dose rate (dr) was determined using the MAZAR gamma spectrometer. The concentrations of ^{226}Ra, ^{228}Th, ^{40}K (Table 2) in each sample were obtained from twenty measurements lasting 2000s each. Equivalent dose (ED) was established on the 63–80 mm polymineral fraction, after 10% HCl and 30% H_2O_2 washing and UV optical treatment. The samples were irradiated with 20 Gy, 30 Gy, 40 Gy, 50 Gy and 100 Gy, dozes from ^{60}Co gamma source. Before measurement, the samples were heated at 140 °C for 3 h. A sample pre-treated in this way was used to determine the equivalent dose (ED) (Table 2) by the TL multiple-aliquot regenerative technique (Wintle and Prószyńska, 1983), according to Fedorowicz et al. (2013). The registration of curves was performed on RA'94 (Mikrolab) thermoluminescence reader, coupled with EMI 9789 QA photomultiplier. The TL age was calculated, according to Frechen (1992). A detailed description of the preparation and the equipment used is contained in Fedorowicz et al. (2013).

2.1.3. U-series dating

Due to reaching the limit of radiocarbon dates, the U/Th method was additionally applied (Table 3). The chemical procedure was done in the U-series Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences (Warsaw, Poland). The method included the thermal decomposition of organic matter and adding the ^{233}U-^{236}U-^{229}Th spike to the samples, which were then dissolved in nitric acid. Uranium and thorium were separated from the hydroxyapatite matrix using the chromatographic method with TRU-resin (Hellstrom, 2003). The isotopic composition of U and Th was measured in the Institute of Geology of the Czech Academy of Sciences, v. v. i. (Prague, Czech Republic), with a double-focusing sector-field ICP mass analyser (Element 2, Thermo Finngan MAT) at low mass resolution ($m/\Delta m \geq 300$). The measurements were corrected to include background and chemical blank in the calculations. The age errors were calculated considering all uncertainties, except decay constant, using error propagation rules. Two cave bear teeth were dated with U/Th method and cross-checked with the use of radiocarbon method.

2.2. Archaeology

2.2.1. Techno-typological analyses

The archaeological assemblage was analysed with the use of a morphometric and technological approach. A set consisting of 33 features was determined for each of the pieces of debitage. The attributes were divided into four general groups:

- general artefact morphology (the size, shape, state of preservation/fragmentation, symmetry, cross-section, profile, the character of the distal part),
- the condition of the dorsal face (the direction of the scars, cortex, interscar ridges, erasing chips, retouch),
- the condition of the ventral face (the bulbs, bulbar scars),
- the condition of the butt (the size, shape, profile, preparation).

Table 2
Thermoluminescence dating of a sediment sample from Koziarnia Cave, layer M (21).

Sample	Lab. No.	^{226}Ra [Bq / kg]	^{232}Th [Bq/ kg]	^{40}K [Bq/ kg]	Dose rate d_r [Gy/ ka]	Equivalent dose/ED (Gy)	TL age [ka]
layer M (21)	UG-7096	13.3 ± 1.4	38.5 ± 3.5	366 ± 37	2.38 ± 0.24	29.0 ± 3.8	12.1 ± 1.8

Table 3
Uranium-series datings of *Ursus ingressus* teeth samples from Koziarnia Cave. The reported errors are 2 standard deviations.

Sample	layer	Lab. no.	U cont. [ppm]	U-234/ U-238	Th-230/U-234	Th-230/ Th-232	Age [ka]
B 129	F (16b)	1124	0.0331 ± 0.0002	1.14 ± 0.01			
B 142	G (16b)	1125	0.0056 ± 0.0001	1.19 ± 0.01			
B 152	G (16c)	1126	0.0275 ± 0.0001	1.22 ± 0.06	0.200 ± 0.009	86 ± 4	24.3 ± 1.3
B 200*	I (17)	1127	0.0458 ± 0.0002	1.16 ± 0.06	0.209 ± 0.007	55 ± 2	25.6 ± 1.0
B 247	L (19)	1128	0.0407 ± 0.0002	1.27 ± 0.08			

* Sample dated also with ^{14}C method (Table 1).

2.2.2. Traceology

Flint artefacts designated for traceological analysis were subjected to a cleaning procedure involving warm water and acetone. The flint material was analysed with a Nikon LV150 metallographic microscope and a Keyence VH-Z100R digital microscope using 50x to 400x magnification. The noted macroscopic and microscopic traces, i.e. chipping, linear wear patterns and signs of usewear, linked to changes in the surfaces caused by postdepositional and utility factors were observed. The traces were interpreted based on a comparison with an experimental reference database, kept together with the relevant documentation at the Institute of Archaeology of the University of Warsaw, as well as with reference to the appropriate literature.

The surfaces of the bone items selected for traceological analyses were cleaned using acetone. The optical-stereoscopic Olympus SZX9 and metallographic Nicon Eclipse LV 100 microscopes were used for the observation of the traces, along with the Nicon Shuttlepix digital microscope with 6.3x to 100x magnification. Natural and technological traces, as well as evidence of usewear were noted on the analysed material.

2.2.3. ZooMS

The ZooMS (peptide mass fingerprinting) analysis followed protocols detailed elsewhere (Buckley et al., 2009; Van doorn et al., 2011; Welker et al., 2016). Bone tools (KZ-2661.4 and KZ-2661.5) were sampled destructively (between 10 and 30 mg) and demineralised in 250 µl 0.5 M HCl at 4 °C for 20 h. The samples were then centrifuged for 1 min at 10 k rpm, and the supernatant was removed. The demineralised collagen was then rinsed three times in 200 µl of 50 mM AmBic (ammonium bicarbonate), and 100 µl of 50 mM Ambic was added to each sample. Next, the samples were incubated at 65 °C for 1 h. Afterwards, 50 µl of the resulting supernatant was digested with trypsin (Promega) at 37 °C overnight, acidified using 1 µl of 20% TFA, and cleaned with C18 ZipTips (Thermo Scientific).

Digested peptides were spotted in triplicate on a MALDI Bruker plate with the addition of an α-Cyano-4-hydroxycinnamic acid matrix. MALDI-TOF-MS analysis was conducted at the Fraunhofer IZI in Leipzig (Germany), using an autoflex speed LRF MALDI-TOF (Bruker) in reflector mode, positive polarity, matrix suppression of 590 Da and collected in the mass-to-range 700–3500 *m/z*. Triplicates were merged for each sample, and taxonomic identifications were made through peptide marker mass identification compared to a database of peptide marker series (A-G) for all medium-to-large sized mammalian species (Buckley et al., 2009; Buckley and Wadsworth, 2014; Kirby et al., 2013).

3. Results

3.1. Stratigraphy

The new fieldwork confirmed the massive destruction of the top part of the original sedimentary sequence. The topmost layer K in the recent cross-section can be correlated with Chmielewski's layer 12 (Fig. 3). There is no possibility to correlate the overlying strata J, B and A, as long as their remnants can be seen only close to the cave walls. All the overlying layers have already been destroyed, mostly due to the 19th-century cave sediment exploitation.

In general, the sedimentary sequence can be divided into four lithostratigraphic series. The lowermost series is red residual clay of weathering origin (P), which has been locally preserved, a remnant of the older sedimentary series (S1). It fills the cracks and fissures in the bedrock. The second series consists of silt and sand (layer M analogical to layer 21 by Chmielewski et al., 1967), filling the bottom erosional rill, most probably a vadose canyon. The third series is built of red-brown and brownish loams (layers H', I, H, I' and L) analogically to layers 17 and 19 by Chmielewski et al. (1967), containing highly corroded and rounded limestone clasts (Fig. 3). The upper series consists of a set of grey loams containing either corroded or sharp-edged limestone clasts. It is divided into two parts by a lamina of red-brown clay, called layer C (14). Layer K', due to considerable amounts of charcoal, was very dark black. It corresponds to layer 13 in Chmielewski's trenches. Forty meters from the entrance in our trench, this layer still contained large charcoal fragments, but it was more yellowish-dark grey. The uppermost part of the section, especially strata situated above layer K' (13), has been disturbed. Layers younger than layer K were preserved only as remnants attached to the wall.

Several erosional surfaces can be identified within the sequence. The most prominent are situated at the bottom of layers I (17), E (16a) and D (15). They are marked as non-conformities. The most distinct is the bottom of layer I (17), which form erosional channels cutting into at least two lower layers H (17) and I' (17).

3.2. Chronology

In total, 14 animal bones and 9 charcoal fragments from the new excavations were dated (Table 1). Radiocarbon dating was conducted on cave bear bones from the old Chmielewski excavations. Additionally, the date was estimated for two ivory tools and the single brown bear bone from Römer's collection (Fig. 4).

The results show that at least some of the strata were contaminated by recent material. Recent dates were obtained solely for the charcoal fragments. This may indicate postdepositional processes connected with the extended exposition of the old open trench walls to external conditions.

Two bones were dated with the use of U-series (Table 3). In order to check the results, one bone was dated with both the radiocarbon and U-series method. The U-series date is distant from the radiocarbon one (Table 1). This suggests that U-series dating is probably unreliable at this site. The reason behind this might be the open uranium system, i.e., the constant availability of uranium ions in the ambient sediments, which resulted in the continuous uptake of U from the environment by bone. In such cases, the U-series dates have only a *terminus ante quem* significance.

Among the newly established dates for the bones, 10 exhibit the atomic C:N ratio in extracted collagen within the accepted range of 2.9–3.6 (Ambrose, 1990; DeNiro, 1985) and indicate well-preserved collagen. One sample (date Poz-99806) yielded too low amount of collagen to measure the C:N ratio, whereas another (date GdA-3896) exhibited too low C:N ratio. Therefore, we decided to discard these dates (Table 1).

The lowermost layers L-M (19–21) yielded two radiocarbon dates. One of them represents recent contamination; the other was established based on material coming from the 1960s excavation; thus, we are not certain about its provenience. Based on the upper layers' dating, layers L-M (19–21) should be regarded as older than ca. 47 ky calBP. The TL

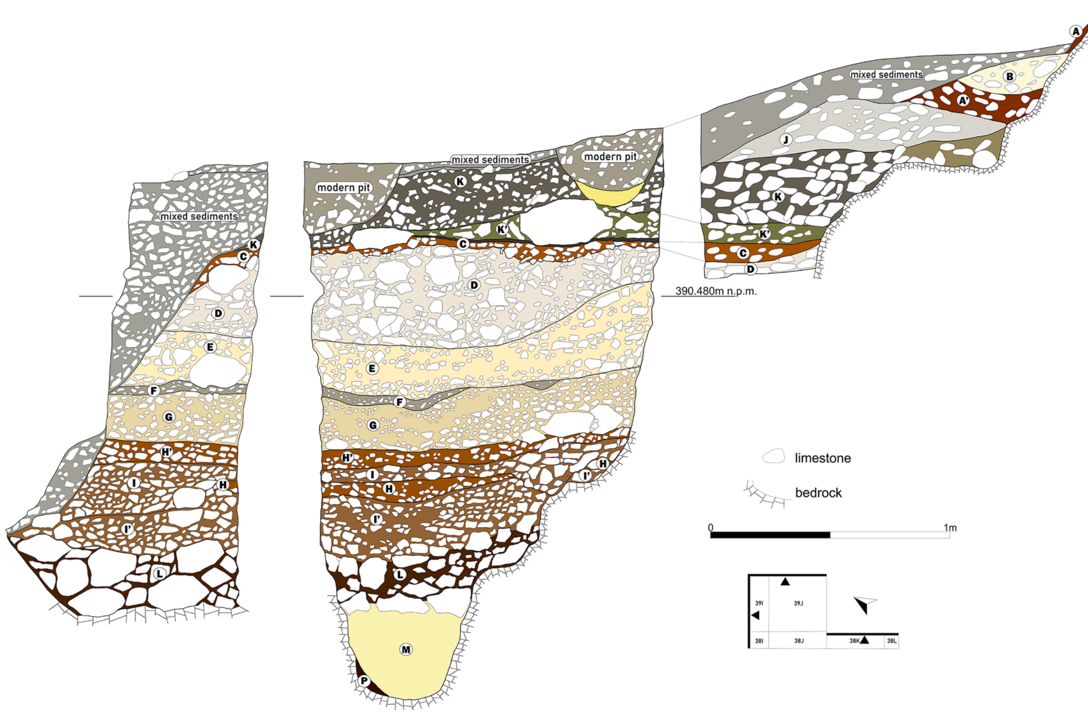

Fig. 3. Northern and eastern cross-sections of trench IX/2017 excavated in 2017 and located in the trench IX corner by W. Chmielewski (drawn by K. Skiba).

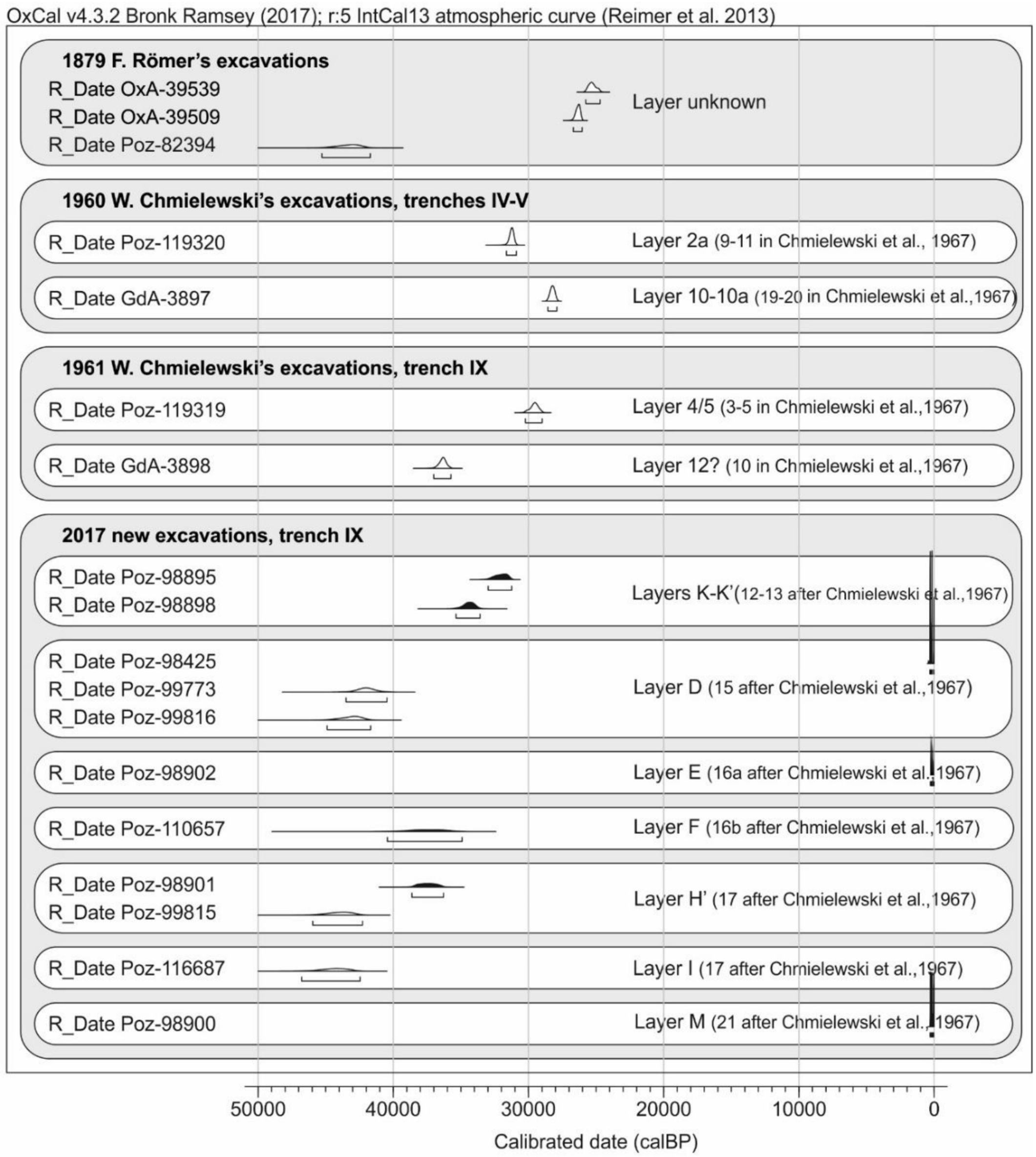

Fig. 4. Calibrated radiocarbon dates from Koziarnia Cave arranged by layers. In black – the dates established for charcoal fragments, in white – for bones or teeth. The open date Poz-99814 and the recent date Poz-98899, which falls beyond the IntCal13 calibration curve, are not shown.

date for layer M (21) is incompatible with radiocarbon dating. This date could be biased due to the close proximity of bedrock, which resulted in a different radiation dose actually absorbed by the sediment than the dose assumed in the laboratory from the measurement of radionuclides' concentration within the sample.

The complex of layers H'/I/H/I' (17) (H' and I, including also the undated layers H and I') exhibits a radiocarbon age of around 47-36 ky calBP. The overlying layer F (16b) shows a slightly younger age, of around 40-35 ky calBP. Layer G was not dated. This chronology is based only on one date (Poz-116687) with a large margin of error (1200 years for 1σ, almost 2500 years for 2σ before calibration). The upper part of the sequence yielded dates, which were not in chronological order with the lower layers. Material from layer D (15) is as old as that from the layer F (16b) and complexes of layers H'/I/H/I' (17). This indicates the erosion of material from the lower stratigraphic position and its re-deposition into layer D. The huge channel-like structure visible in the bottom of layer D supports this hypothesis. Layers K (12) and K' (13) provided dates of around 35-31 ky calBP. This remains in accordance with the dating of layer F, especially if we consider the large margin of error for a single date from these layers. This also indicates that the erosion event followed by the redeposition of layer D should be dated to around 37 ky calBP.

Two ivory tools found in the F. Römers collection (Fig. 5) were dated to 25-26 ky calBP (Table 1), which are younger than the chronology of the uppermost layers K (12) and K' (13) excavated in 2017. These radiocarbon dates indicate the presence of most likely later Gravettian occupation in Koziarnia. It was most probably connected to one of the layers already destroyed in the cave. Moreover, the spectra obtained from both specimens in ZooMS analysis were taxonomically identified as Elephantidae. The marker series are similar for some closely related species. In this case, possible species can belong to the *Elephas*, *Mammuthus* or *Palaeoloxodon* genera. Considering the archaeological context, these two bone tools were most likely manufactured from woolly mammoth remains, which is supported by the radiocarbon dates.

3.3. Archaeological data

During new fieldwork, almost 1000 stone artefacts were collected

Fig. 5. Ivory artefacts found by F. Römer in Koziarnia Cave. (a) Fragment of broken ivory with a smothered ending. (b) Fragment of ivory point with incisions. Photo M. Bogacki.

(S4, S6). Table 4 shows the composition of artefacts found in each geological stratum. Not all artefacts could be undoubtedly attributed to geological layers because of the opening of a new trench in the corner of the old collapsed one and excavating not only stratified sediments but also partly collapsed and moved layers (Table 4). Within the majority of layers, the number of collected lithics did not exceed 20 pieces each. Excluding mixed materials, only layers D, K/K', H' and I' are relatively richer.

Most of the artefacts are tiny chips and chunks; they constitute, on average 69% of the assemblage. The average stone artefact size is 7.35 mm in length, 5.84 mm in width, and 2.65 mm thick. No cores or preforms were found within the assemblage. The small size of the artefacts can be explained by the trench's location, which was situated 40 m from the entrance to the cave. One can expect scarce human activities held so far from the entrance.

Overall, 27% of all the flint artefacts had postdepositional retouches, and 35% of them had undergone postdepositional breakage. The highest impact of postdepositional processes was observed in layers I and I'. The state of preservation and small dimensions of the artefacts cause it to be difficult to identify potential traces resulting from the use of individual flint specimens. The surfaces were deformed to a high extent and covered with shiny or white patina. In addition, some parts of the edges were destroyed, an effect of which were numerous postdepositional chippings, which stand out due to the distinctive "freshness" of the flake negatives as compared to the preservation state of the remaining parts of the specimen surfaces. Apart from layers K/K' (12/13), where characteristic retouched pieces attributed to Gravettian were found (Fig. 6), the other layers contained mostly uncharacteristic debitage, prevalently chips.

The stone artefacts analysis indicates traces of Jerzmanowician occupation in layer D (15) (S4). The most prominent are the ventral thinning chips (Kot et al., 2021) and the debitage with bidirectional scars (Fig. 7). A bidirectional knapping scheme is also confirmed by a big blade detached from a bidirectional core found in the same layer by W. Chmielewski (Fig. 7: IX/17-23/61).

4. Discussion

4.1. Koziarnia—Correlation of layers

The stratigraphy observed in the 2017 trench fits well the description and documentation of trench IX by W. Chmielewski. The only difference is the presence of at least four separate strata, which were treated as a unified layer 17 by W. Chmielewski. Based on the new fieldwork, one can differentiate at least four substrata within the layer 17, differing due to the presence of weathered limestone clasts and the colouration (from the top: layers H', I, H, I') (Fig. 8). Traces of the relatively most intensive human occupation were found in the uppermost layer H' and the lowermost layer I'.

The second difference between Chmielewski's cross-section and the recent study is the relatively small amount of charcoal found in layer K', which can be correlated with layer 13 by Chmielewski. Nonetheless, this layer contained the highest number of charcoal fragments in the entire sequence. However, their concentrations did not change the colouration of the stratum, as observed by Chmielewski in trenches IX and especially IV & V. As long as these layers can be correlated with human occupation, one can presume that the highest charcoal concentration could indicate an occupation zone, which weakens as it nears the end of the cave corridor.

Comparing all available cross-sections from the previous fieldwork enables the reconstruction of the layers' general correlation (Fig. 8). The trenches located in the entrance zone revealed a thick Holocene sequence of humic horizons and underlying loess layers, which can be divided into two separate horizons. The loess sediments can be correlated with units 'A' and 'C' and dated to the late MIS 3 and MIS 2 according to the comparison with other caves in the same region and the lithostratigraphic scheme by Krajcarz et al. (2016). However, we do not have any direct dating data. All the older strata were probably washed away from the entrance zone before the late MIS 3. The most problematic issue linked to the whole stratigraphy of the Koziarnia Cave is the almost absolute destruction, removal and mixing of the sediments of the main chamber, which was probably the central settlement zone with the highest concentration of artefacts. The original stratigraphic remnants can be found only attached to the regolith visible on the main corridor's wall. The current cave infilling contains only layers dated to MIS 3, except for the lowermost strata M (21) and P, which might be older.

Based on the artefacts found and the obtained dates, one can see at least four different Palaeolithic settlement episodes in the cave. The Middle Palaeolithic is connected to layers 17 (H'/I/H/I') and 18 (L), Jerzmanowician – to layers 15-16 (D-E-F-G), and the Early Gravettian – to layers 13-12 (K-K'). The later probably Gravettian episode (25-26 ky calBP) cannot be attributed to any particular stratum but was manifested by two bone tools found in F. Römer's collection.

The layers' general correlation shows that the charcoal amount in the Early Gravettian horizon diminishes towards the end of the cave and is the most intense approximately 20–25 m from the entrance. In contrast, the thickness of the Jerzmanowician layers 15–16 increases as they near the end of the cave (a 75-cm-thick layer is 40 m from the entrance), while they disappear at the cave entrance.

4.2. Chronology

Most of the established dates cover the period between 46 and 24 ky calBP. However, several charcoal datings provided unexpectedly recent ages (Table 1). Based on the taxonomical analysis of the charcoal assemblages, it can be assumed that a part of the floated samples was indeed contaminated, which is confirmed by a few samples of charcoal fragments containing to fir *Abies alba*, hornbeam *Carpinus betulus* and beech *Fagus sylvatica*. These trees are considered late-coming species in the vegetation history of Poland related to the late Holocene (Ralska-Jasiewiczowa et al., 2004). Such samples came mostly from areas

Table 4
General composition of the Koziarnia Cave archaeological lithic assemblage.

Layer	No of lithics artefacts	Average size (mm)	flakes (%)	blades (%)	chips (and termic chips) (%)	chunks (%)	pieces with cortex	tools/ flakes with genuine retouch (%)	postdepositional retouch on artefacts (%)	pieces broken postedpositionaly or undeterminably	pieces with postdepositional retouch or breakage, edge abrasion
A	5	6.1x5.2x2.2	0	0	2	3	2	0	0	0	0
J	5	8x6.1x2.8	2	0	0	3	0	1	0	2	3
J/K/ mixed	7	6.6x5.2x2.3	3	0	0	4	3	1	1	3	4
K + K' (12 + 13)	139	7.7x6.1x2.7	$44^{(31.7\%)}$	$9^{(6.5\%)}$	$33^{(23.7\%)}$	$53^{(38.1\%)}$	$38^{(27.3\%)}$	$11^{(8.4\%)}$	$13^{(9.4\%)}$	$40^{(28.8\%)}$	73
C (14)	7	8,5x6.4x2.8	2	0	3	2	1	0	2	2	4
C/D (14/ 15)	12	9,2x5x2,6	4	0	0	8	4	0	2	4	4
D (15)	125	7.4x5.9x2.6	$35^{(28\%)}$	$2^{(1.6\%)}$	$45^{(36\%)}$	$43^{(34.4\%)}$	$24^{(19.2\%)}$	$2^{(1.6\%)}$	$19^{(15.2\%)}$	$31^{(24.8\%)}$	69
E (16a)	6	5.3x4.5x2.3	2	0	2	2	0	0	1	3	4
E/G (16a/ 16c)	1	3,5x2,5x0,5	0	0	1	0	0	0	0	0	0
F (16b)	1	17x11x7	0	0	0	1	0	0	1	0	1
G (16c)	14	6.4x5.2x2.5	2	1	0	11	2	0	1	3	5
G/H' (16c/ 17)	1	4x2x1.5	0	0	0	1	0	0	0	0	0
H'/I/H/ I' (17)	435	7.3x5.8x2.6	$104^{(23.9\%)}$	$3^{(0.68\%)}$	$132^{(30,3\%)}$	$196^{(45.1\%)}$	$104^{(23.9\%)}$	$5^{(1.1\%)}$	$60^{(13.8\%)}$	$133^{(30.6\%)}$	108
L (19)	18	11x8.5x5	8	0	3	7	4	2	1	4	9
M (21)	8	7.7x6.1x2.7	1	0	4	3	3	1	0	0	2
Mixed	194	7.4x5.8x2.7	44	7	55	88	50	5	29	53	106
Total	978	7.3x5.8x2.6	251	22	280	425	235	28	130	278	392

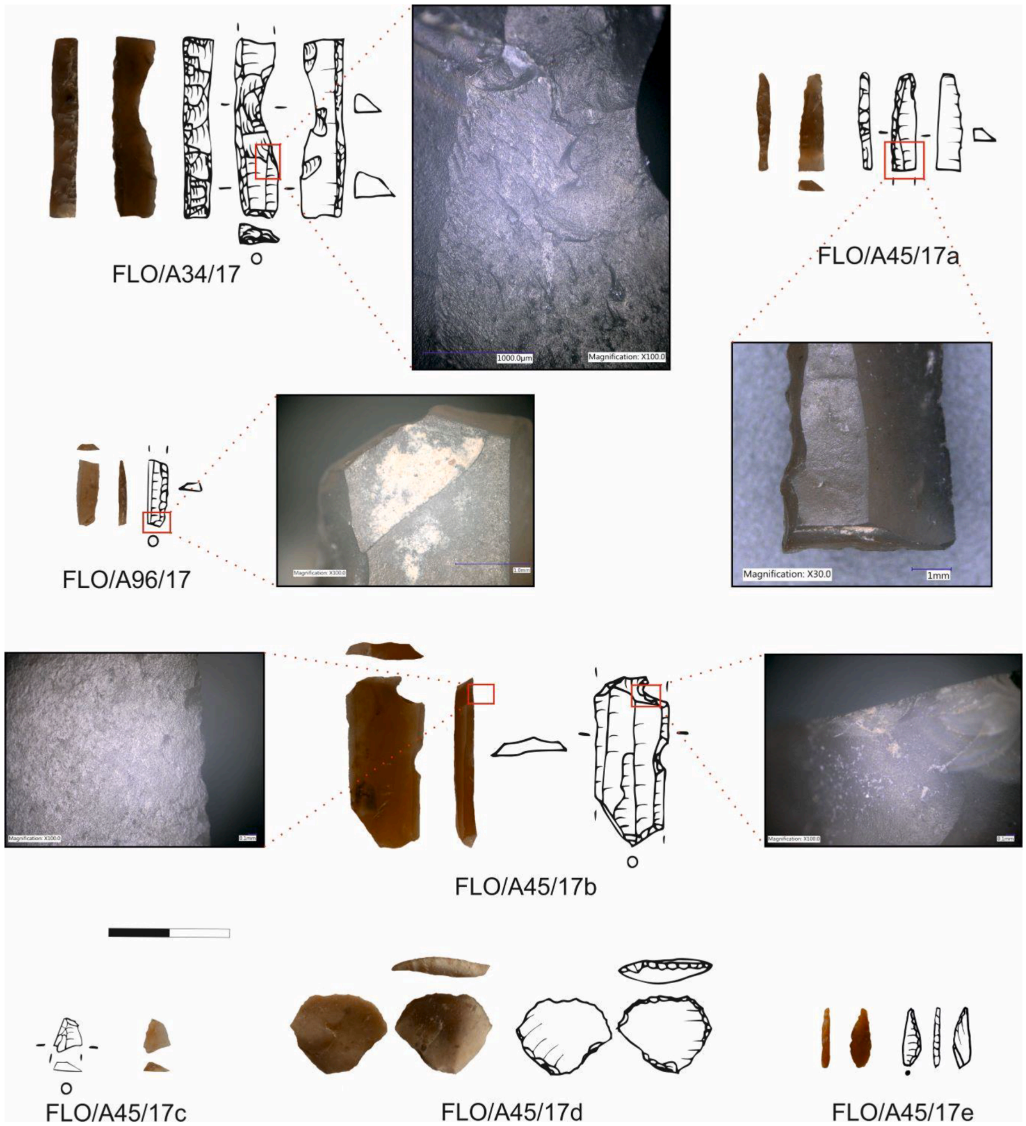

Fig. 6. Gravettian artefacts found in Koziarnia Cave, layer K (12) and K' (13) in trench IX/2017. Detailed traceological analysis results are presented in S5.

located near the previous excavations. After preliminary analysis, the existence of postdepositional disturbances was confirmed, indicating that these places should be excluded from chronological inference. However, in a few other samples, only coniferous taxa were found (juniper *Juniperus communis* and pine *Pinus* type *sylvestris-mugo*), suggesting that they could have originated from the Pleistocene layers, but their radiocarbon dating results showed also a modern contamination (Table 1). This analysis evidenced that the very meticulous study of strata in the context of all archaeological and biological findings is needed to understand taphonomic processes in cave sites.

Another explanation for the observed discrepancy between the dates achieved from bones and charcoal includes the altered ^{14}C content in the charcoal fragments. From a recent study (Hercman et al., 2019), we know that carbon in wood during the high temperature processing (such as burning) is subjected to kinetic fractionation of isotopes. Namely, charcoal from coniferous wood burned in low temperatures is enriched in heavy carbon and oppositely, burned in higher temperature (400–600 °C) is depleted in heavy carbon in relation to the original wood. If dated charcoals were burnt in relatively low temperatures, e.g. in the outer part of the fireplace, radiocarbon dates might be rejuvenated.

It is worth noting that layer D's radiocarbon dates are not in the correct order with those from the lower strata (Fig. 4). This can be an effect of the mentioned isotopic fractionation in burnt wood, or likely the effect of redepositional episodes, possibly related to the erosional structures visible in layers E and D. The directions of this transport are difficult to reconstruct as the 2017 excavation area was relatively small and delivered minimum data on the geometry of sedimentary structures. Moreover, the topography of the cave floor was disturbed due to the previous exploitation. However, the higher elevation of sediments in the area closer to the entrance (especially visible in W. Chmielewski's trench at the 30th metre) may suggest that this area served as source material for colluvial activities. We can hypothesise that at least some dates from the upper layers represent a redeposited material. In this case, we need to accept that the faunal, anthracological and archaeological assemblages from these layers could also have been affected by colluvial mixing.

If we look at the distribution of the probability density of radiocarbon dates regardless of the stratigraphy (Fig. 9), we can detect several phases of dated material deposition. The deposition phases of the animal remains took place ca. 46-41 ky calBP, ca. 37-35.5 ky calBP, and ca. 32-28.5 ky calBP. The dates from charcoal fragments are restricted to ca. 39-31 ky calBP, while the dated ivory tools to ca. 26.5-24 ky calBP. Assuming that charcoal fragments are the remnants of hearths, the

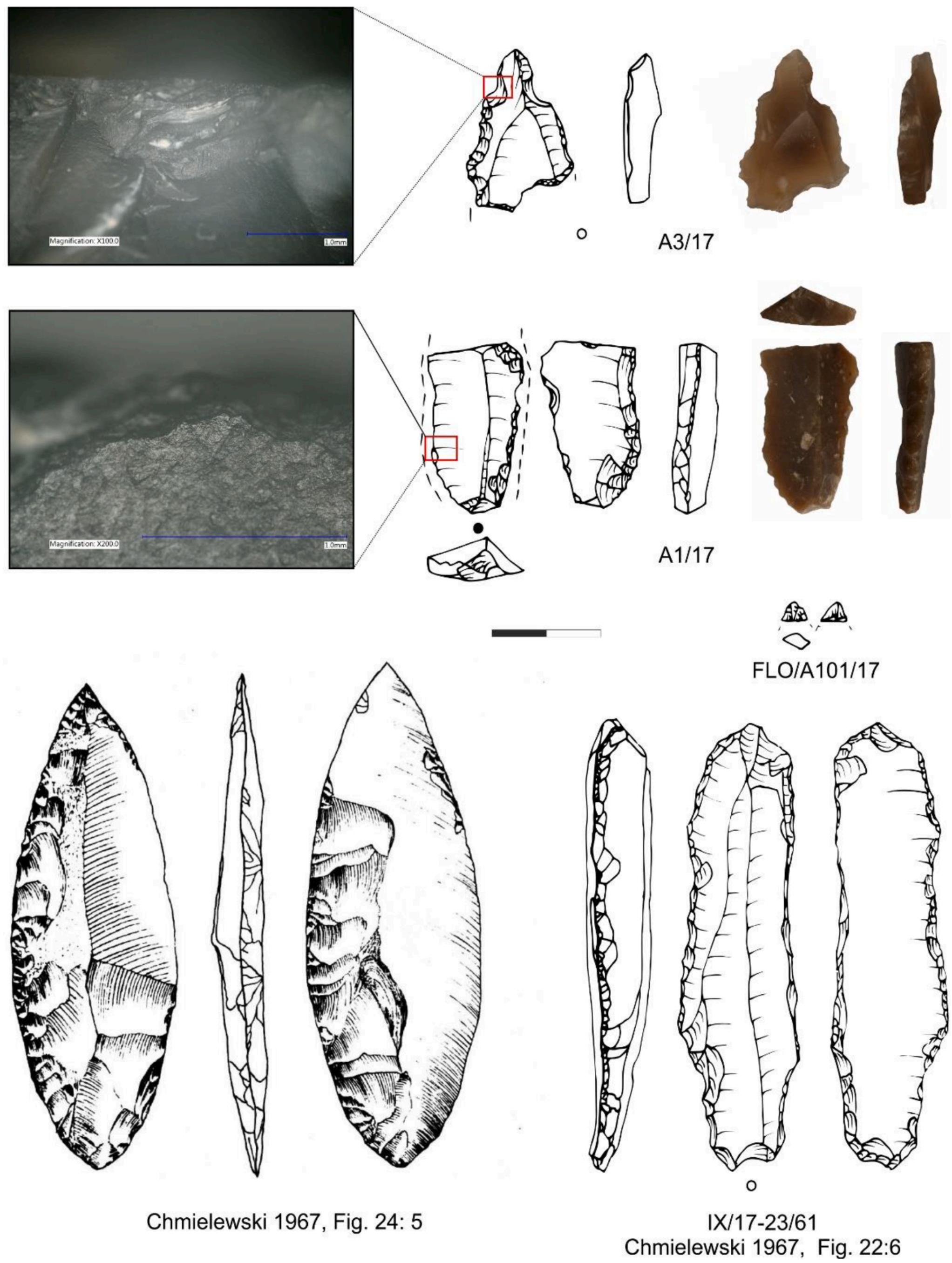

Fig. 7. *Artefacts from Koziarnia Cave attributed to Jerzmanowician. Flake (A3/17) and a tip of bifacially worked artefact (FLO/A101/17) were found in trench IX/2017 in layer D (15); Blade with ventral thinning (A1/17) was found in mixed sediment in trench IX/2017; Leafpoint was found by F.Römer in the second half of 19th century (*Römer, 1883*); IX/17–23/61- blade made on double platform core found by W. Chmielewski in layer 17 of trench IX, later called layer 15 in the final publication (*Chmielewski et al., 1967*).*

probability density of radiocarbon dates for charcoal represents the human settlement phase. During this phase, we can identify three weakly separated subphases. The first one can be dated to ca. 39-36 ky calBP (represented by two dates) whereas the second to ca. 35-33.5 ky calBP (a single date), and the third to ca. 33-31 ky calBP (a single date). Due to the samples' stratigraphic position, we may assume that the first phase is connected with Jerzmanowician occupation, while the second and third with Early Gravettian. The last human settlement phase in 26-24.5 ky calBP also represents traces probably of the Gravettian occupation. Another phase, not shown in Fig. 9, is the modern one (around 300 y BP until modern times), based on the most recent dates achieved for the charcoal.

It is worth noting the alternate occurrence of dates determined for charcoal fragments and animal remains (Fig. 9). All the dated animals were bears, mostly the cave bear, but one date was also established for the brown bear. Bears used the caves as hibernation dens, and their presence in a cave could not be contemporaneous with human settlement (Wojtal et al., 2015; Terlato et al., 2019). Our dataset indicates that Koziarnia Cave indeed was alternately occupied by humans and bears.

In Fig. 9, we compared the distribution of the probability density of radiocarbon dates with the pattern of the revised δ^{18}O curve in the Greenland ice core. The curve represents reliable climate proxy reflecting northern hemispheric climatic changes in the Pleistocene (Cooper et al., 2015; Rasmussen et al., 2014; Seierstad et al., 2014). If we consider the dates obtained for charcoal fragments and bone tools, which are direct indicators of human settlement in Koziarnia Cave, we can notice interesting relationships. Three peaks of the charcoal date distribution correspond to three warmer periods (Greenland interstadials, GI-8, GI-6 and GI-5.2), whereas the minima of this distribution coincide with colder periods (Greenland stadials, GS-8 and GS-6).

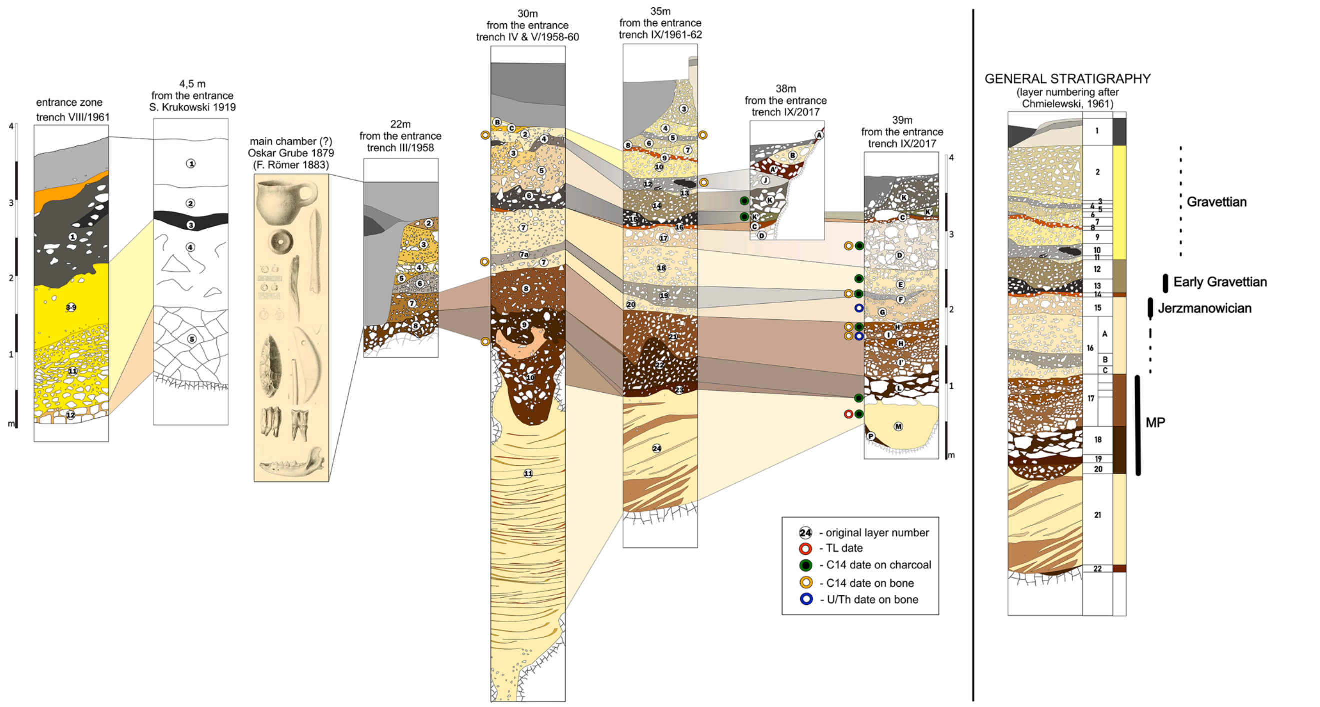

Fig. 8. *Correlation of all the profiles obtained during subsequent archaeological fieldworks in Koziarnia Cave with a location of samples used for dating. S. Krukowski field documentation* (Kot et al., 2019; Kozłowski, 2007) Kozłowski, 2007*, artefacts found by F.* Römer (1883); *W. Chmielewski profiles redrawn after* Chmielewski et al. (1967) *and field documentation of trench VIII, trench IV, V & IX.*

Although the date distribution for bone artefacts is shifted to Greenland stadial GS-3, there is a clear gap between these two distributions, which corresponds to the coldest stadial GS-5.1. This result suggests that Koziarnia Cave could be inhabited by human groups in waves, especially in warmer periods, whereas climate cooling could discourage people from settling in this place. Interestingly the recent multiproxy palaeoenvirinmental results obtained in Koziarnia Cave do not show traces of warming during the GI 8 (Berto et al., 2021).

4.3. Other sites—Correlation of profiles

Jerzmanowician assemblages are known from Nietoperzowa, Mamutowa, Puchacza Skała and Shelter above the Zegar Cave sites in Poland (Chmielewski, 1961; Kowalski et al., 1965; Kowalski, 1967; Kozłowski, 1922; Krajcarz et al., 2012). The stratigraphic correlation of Jerzmanowician-bearing strata from Koziarnia Cave and Nietoperzowa Cave was studied by T. Madeyska-Niklewska and was first presented by Chmielewski et al. (1967) and then by Madeyska-Niklewska (1969). According to this interpretation, layer 15 (D) from Koziarnia, where we found traces of Jerzmanowician occupation, correlates with layer 10b of Nietoperzowa Cave. However, the Jerzmanowician settlement is well-known from the younger layers 4-5-6 of Nietoperzowa Cave.

It is difficult to compare both caves' sequences based on the lithology, as they represent rather different facies (Fig. 10). Sediments from Nietoperzowa Cave are mostly silty loams with limestone clasts, deposited in the near-entrance area under the strong influence of aeolian activity. In Koziarnia Cave, the recognised sediments are coarser, they were deposited quite deep inside the cave, and they are mostly limestone debris. However, the proportion of angular to subangular clasts, presented by Madeyska-Niklewska (1969), enables correlating the Jerzmanowician layer 15 (D) from Koziarnia Cave with either the lowermost or the uppermost Jerzmanowician-bearing strata from Nietoperzowa Cave, namely layers 6 or 4.

In Mamutowa Cave, the Jerzmanowician assemblage was found in layer VI (Kowalski 1967, 1969; Lorenc, 2006; Madeyska, 1992), which was blackish due to a significant concentration of charcoal (Fig. 10). Unfortunately, a detailed stratigraphic comparison between Koziarnia and Mamutowa caves is restricted due to the sediment's different character at both sites. Kowalski's layer V overlying the Jerzmanowician horizon was mostly loess sediment, which is not present inside the gallery in Koziarnia.

Interesting conclusions can still be derived from a comparison of the radiocarbon chronology of Koziarnia Cave with other sites of the Middle/Upper Palaeolithic transition and early Upper Palaeolithic from southern Poland (Fig. 11). The Jerzmanowician assemblages' chronology is currently based on 38 radiocarbon dates (Krajcarz et al. 2018; S3). The majority of the radiocarbon datings were obtained on either cave bear ($n = 29$) or bird ($n = 4$) bones without human activity traces. Taking into consideration the fact that cave bears and possibly also birds of prey did not cohabit the caves with humans, in order to determine the chronology of human occupation, we shall instead rely on radiocarbon dates provided by charcoal, bones with cut marks, or animal species that do not naturally live in caves, such as mammoths. If we take this into account, one can limit the list of reliable dating for LRJ into four cases, i. e.:

- 33,100 ± 1200 BP (wood charcoal, Koziarnia Cave, layer F, Poz-110657, this study);
- 33,230 ± 480 BP (wood charcoal, Koziarnia Cave, layer H', Poz-98901, this study);
- 32,500 ± 400 BP (woolly mammoth, Nietoperzowa Cave, layer 5b, Poz-23628, Nadachowski et al., 2011);
- 38,160 ± 1250 BP (wood charcoal, Nietoperzowa Cave, layer 6, Gro-2181, Chmielewski, 1961).

As long as the oldest date was obtained from the lower Jerzmanowician layer in Nietoperzowa Cave, one can assume that the presented set of dates demonstrates two separate settlement episodes. In such a case, the Jerzmanowician settlement in Koziarnia Cave could be tentatively correlated with the upper Jerzmanowician horizon in layer 4 in Nietoperzowa Cave, and represent the younger phase of Jerzmanowician.

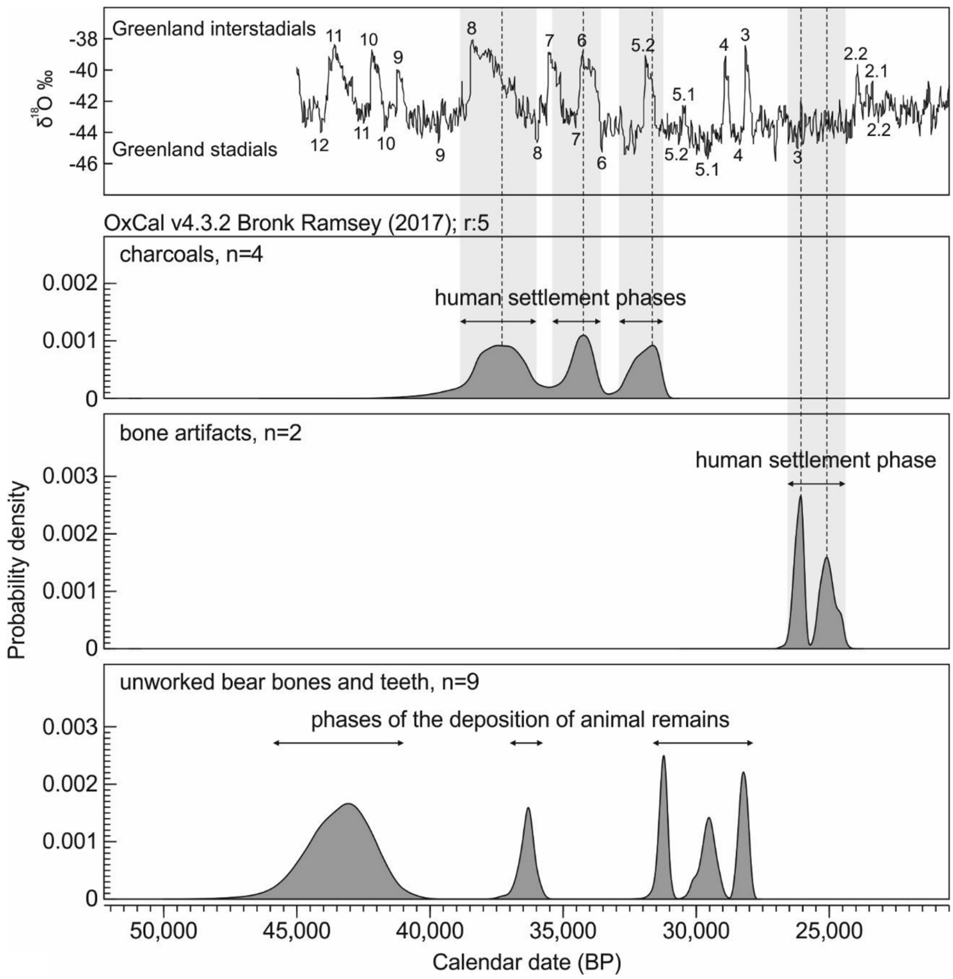

Fig. 9. *Distribution of the probability density of calibrated radiocarbon dates for Koziarnia Cave obtained for charcoal fragments (pink) and bone tools (yellow) compared with the revised $\delta^{18}O$ curve in the Greenland ice core (blue) obtained by combining the Cariaco Basin (Hulu Cave) and Greenland ice core (GICC05) records (Cooper et al. 2015). Corresponding Greenland stadials (GS) and interstadials (GI), as determined by Rasmussen et al. (2014) and Seierstad et al. (2014) are indicated by numbers placed below or above the $\delta^{18}O$ curve, respectively. The four most recent dates are excluded.*

Moreover, one should consider the radiocarbon dates obtained recently on two bone points of the Mladeč type from Mamutowa Cave (38,5-36,5 ky calBP- S2), which overlap with those from Koziarnia Cave. Although Mladeč-type points are still believed to represent rather the Aurignacian tradition, in Mamutowa Cave, no other Aurignacian artefacts were found either by Zawisza (1882a, 1882b) or Kowalski (1967, 1969). Kowalski, who studied stratigraphy in detail, determined a single Jerzmanowician layer (VI) and Gravettian occupation traces in loess layer 2. The radiocarbon-dated bone point comes from the old excavations by Zawisza; thus, their original stratigraphic position is impossible to establish, besides the information that they came from the inner part of the section.

The recent project on the ^{14}C dating of the available Early Upper Palaeolithic bone points shows that they represent a broad chronology starting from 43 up to 34 ky calBP (Davies et al. 2015). At several sites (Istallöskö, Dzerava Skala), such bone points were found in the company of leafpoints (Dobosi, 2002; Hillebrand, 1910; Kaminská et al., 2004, 2005, Markó, 2015, 2017). Moreover, traces of Aurignacian occupation in Poland are very scarce and limited to several sites, e.g. Piekary II, Obłazowa layer VIII and Góra Puławska (Sachse-Kozłowska, 1978; Valde-Nowak et al., 2003; Valladas et al., 2003). The only available radiocarbon date indicates that the earliest Aurignacian settlement started around 36 ky calBP and is slightly younger than both bone points from Mamutowa Cave and the Jerzmanowician occupation in Koziarnia Cave. Nevertheless, one should stress the presence of Aurignacian occupation dated to 37-33 ky calBP to the south of Carpathians e.g. in Mladeč Cave, Milovice I, Vedrovice Ia, or Stránská skála and Líšeň open-air site complexes (Demidenko et al. 2017).

The bone points from Mamutowa Cave are older than the oldest available Aurignacian dating north of the Carpathians, but at the same time, they overlap with the Jerzmanowician settlement in Koziarnia and Nietoperzowa Caves. One can, therefore, assume that they could have originally belonged to the Jerzmanowician assemblage in Mamutowa Cave. Unfortunately, Mamutowa Cave's chronology is mostly based on radiocarbon dates made on cave bear and bird bones. The sets of dates from underlying and overlying strata as well as from layer VI indicate some postdepositional sediment mixing (S2).

The possibility of the long chronology of the LRJ technocomplex exceeding the Campanian Ignimbrite (CI) eruption event is also confirmed by results obtained in Lincombian sites, e.g. Beedings, indicating its lasting up to even 30 ky BP (Pope et al., 2013; Jacobi, 2007).

4.4. Gravettian occupation

It is noteworthy that aside from the Middle Palaeolithic and Jerzmanowician, also two Gravettian occupation phases can be identified in Koziarnia Cave. The first one could be correlated with the second and third human settlement phase recorded by the charcoal dated to 35-31 ky calBP (Fig. 11). This dating overlaps with the earliest traces of Gravettian hunters' penetration, confirmed recently in Henryków 15 in the Sudetes piedmonts. The chronology of the settlement traces in Koziarnia Cave indicates that the earliest Gravettian groups penetrated the nearest vicinities of the Moravian Gate and went much further into the Polish Highlands.

The second settlement phase, which is recorded only by two ivory tools of uncertain stratigraphic positions, indicates probably Gravettian

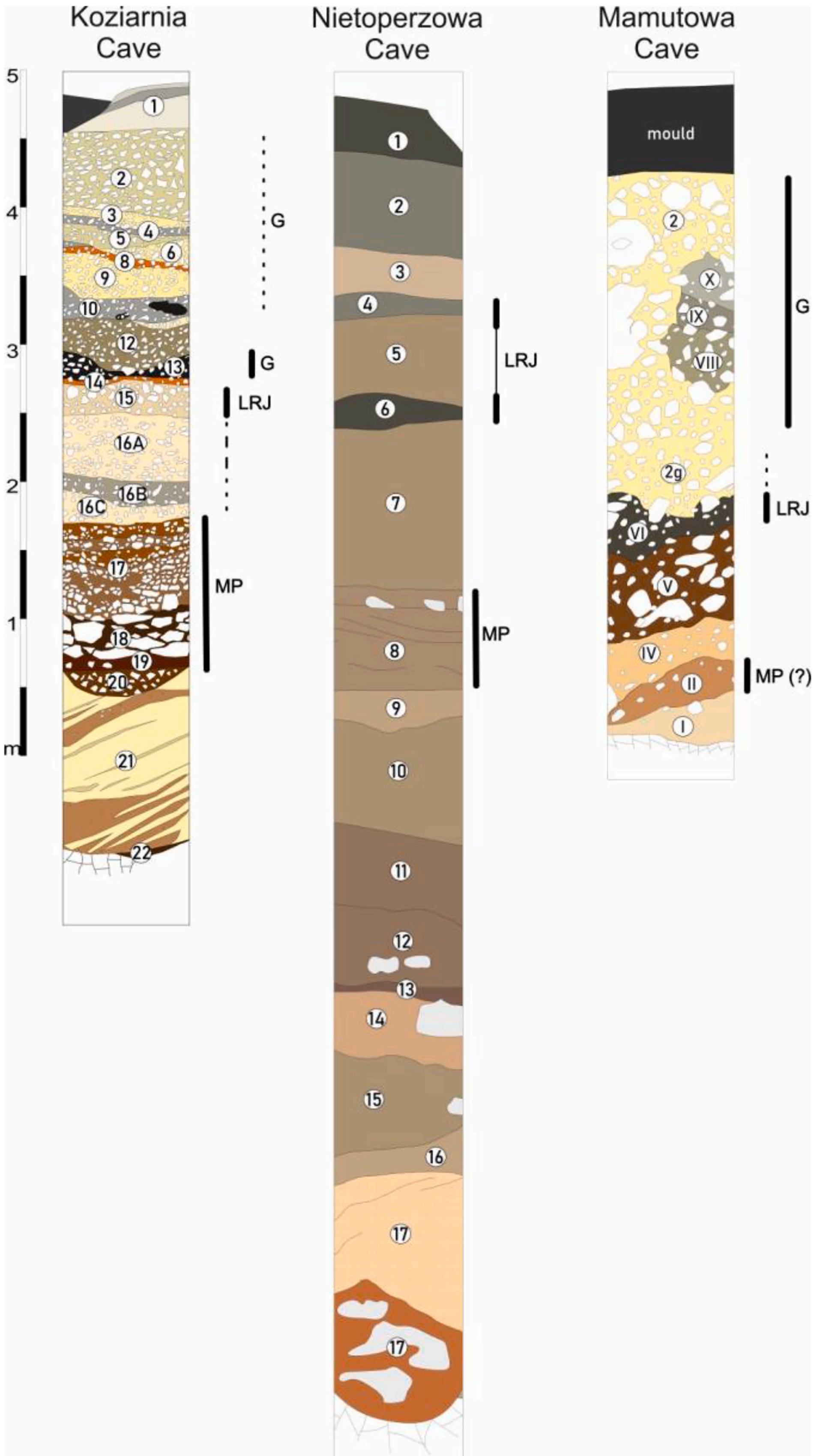

Fig. 10. *Correlation of profiles from three Jerzmanowician sites: Nietoperzowa Cave (Krajcarz et al., 2018), Mamutowa Cave (Madeyska, 1992; Lorenc, 2006) and Koziarnia Cave. Symbols used: G- Gravettian; LRJ - Lincombian-Ranisian-Jerzmanowician; MP - Middle Palaeolithic.*

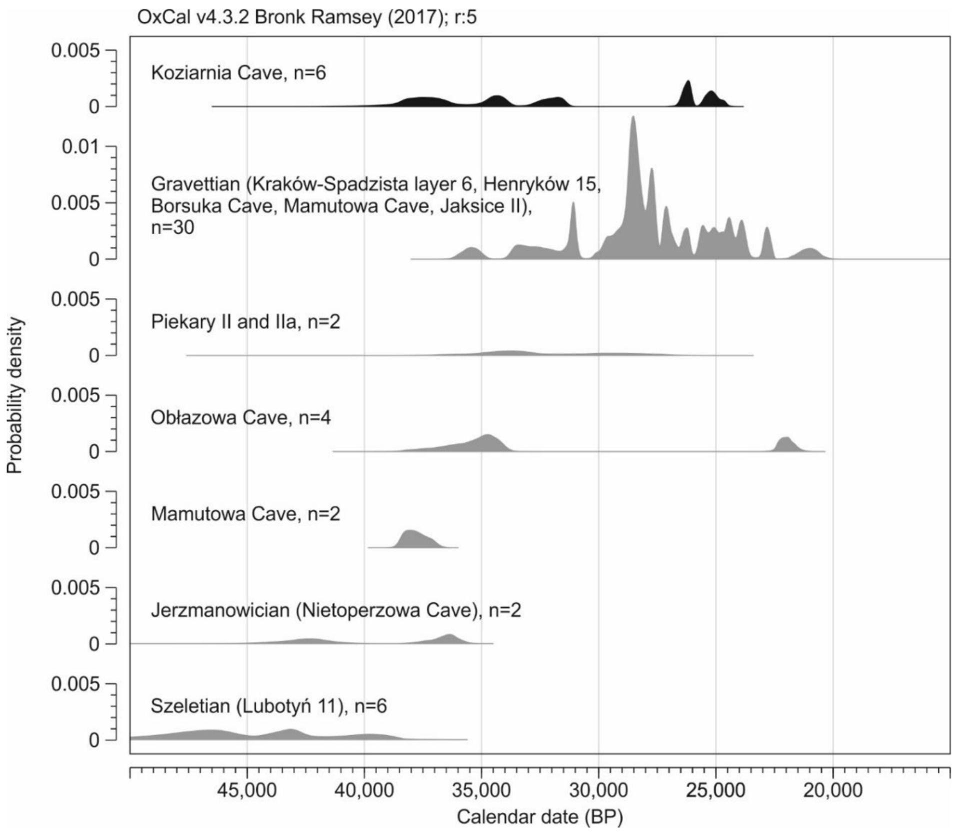

Fig. 11. *Correlation of the probability density distribution of radiocarbon dates from Koziarnia Cave, Middle-to-Upper Palaeolithic transition sites and early Upper Palaeolithic sites from southern Poland (S2). Only the dates representing human settlement are regarded here (in the case of multi-strata cave sites – only the charcoal and reworked bones/ivory; in the case of single-stratum open-air sites – all the dates from a cultural layer). Dates after* (Arppe and Karhu, 2010; Bobak et al., 2013; Chmielewski, 1961; Davies et al., 2015; Kozłowski and Sobczyk, 1987; Nadachowski et al., 2011; Pettitt, 2004; Valladas et al., 2008; Wilczyński, 2015; Wilczyński et al., 2012a,b, 2015; Wiśniewski et al., 2015; Wojtal, 2007; Housley, 2003; Połtowicz-Bobak et al., 2013).

occupation in Koziarnia Cave simultaneous to a well-known mammoth butchering site at Spadzista Street in Kraków (Wojtal and Sobczyk, 2003, 2005; Wojtal et al., 2015). Interestingly, none of the Gravettian occupation phases in Koziarnia Cave overlap the Gravettian settlement from Mamutowa Cave, dated to 29-27.5 ky calBP.

5. Conclusions

The new research shows the developed stratigraphy in Koziarnia Cave and a much more complex archaeological situation identified by previous researchers. Although the new fieldwork was conducted far from the cave entrance, detailed chronostratigraphic and archaeological analyses made it possible to determine at least four occupation phases in the cave.

The cave was occupied for the first time in the Late Middle Palaeolithic (MIS 3), but the assemblage's typo-technological character is still to be discussed due to both Levallois like cores and bifacial pieces within the MP assemblage (S4; Chmielewski et al., 1967). The obtained results confirm that the site was indeed occupied during the Middle/Upper Palaeolithic transition, as supposed after the discovery of the bifacial leafpoint in 1879 (Römer, 1888). This occupation phase, identified as Jerzmanowician, can be correlated with layers D-G and be dated to 39-36 ky calBP. The obtained radiocarbon dates indicate that the Jerzmanowician tradition lasted longer than it was previously supposed. The new dates indicate that Jerzmanowician tradition did not finish with the Campanian Ignimbrite eruption.

Above the Jerzmanowician strata, a thin, sterile layer can be observed, separating the overlying strata containing Gravettian artefacts. The earliest Gravettian occupation can be dated to 35-31 ky calBP, and thus represents the earliest Gravettian occupation in the Polish Jura, and one of the earliest to the North of Carpathians. The obtained radiocarbon dates from the ivory tools found in the cave in the 19th century indicate the latter Gravettian settlement phases.

One should also emphasise that the recent results confirm the previous assumptions, claiming that humans and animals did not cohabit caves, even if their traces are found in the same lithostratigraphic layers. For this reason, only radiocarbon dates obtained either from charcoal fragments and bones or teeth processed by human should be used for determining human settlement at cave sites.

CRediT authorship contribution statement

Małgorzata Kot: Conceptualization, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Funding acquisition, Supervision. **Maciej T. Krajcarz:** Conceptualization, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Magdalena Moskal-del Hoyo:** Formal analysis, Writing - original draft, Writing - review & editing. **Natalia Gryczewska:** Formal analysis, Investigation, Writing - original draft, Visualisation. **Michał Wojenka:** Formal analysis, Writing - original draft. **Katarzyna Pyżewicz:** Formal analysis, Writing - original draft. **Virginie Sinet-Mathiot:** Formal analysis, Writing - original draft, Writing - review & editing. **Marcin Diakowski:** Formal analysis, Writing - original draft, Writing - review & editing. **Stanisław Fedorowicz:** Formal analysis. **Michał Gąsiorowski:** Formal analysis, Writing - review & editing. **Adrian Marciszak:** Resources, Funding acquisition. **Grzegorz Lipecki:** Resources. **Paweł Mackiewicz:** Resources, Writing - review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors would like to thank Professor Teresa Madeyska, who gave access to the site's archive field documentation and provided generous support in our research. We want to thank the Ojców National Park and the Institute of Geophysics of the Polish Academy of Sciences for their kind permission for conducting the fieldworks inside the cave. The Max Planck Society financed the ZooMS analysis, and we would like to acknowledge Prof. Dr Stefan Kalkhof and the IZI Fraunhofer institute of Leipzig for providing us access to the equipment allowing the ZooMS analysis. We are thankful to the Archaeological Museum in Wrocław for permitting to conduct radiocarbon and ZooMS analyses on the ivory tools. The archaeological fieldwork and chronostratigraphic studies were financed by the National Science Centre, Poland within a framework of the project no. 2016/22/E/HS3/00486. The National Science Centre of Poland financed the radiocarbon dating (Poz-82394), awarded to Adrian Marciszak within the scope of the Grant "The history of the brown bear *Ursus arctos* Linnaeus, 1758 evolution in Central Europe as a key to modern species conservation" no. 2015/17/D/ST10/01907. Radiocarbon datings of cave bear (GdA-3896- GdA-3898) were financed by the National Science Centre, Poland grant no. 2012/07/B/NZ8/02845 awarded to Paweł Mackiewicz. We would like to thank three anonymous reviewers for their great effort to improve the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2021.103014.

References

Alex, B., Valde-Nowak, P., Regev, L., Boaretto, E., 2017. Late Middle Paleolithic of Southern Poland: Radiocarbon dates from Ciemna and Obłazowa Caves. J. Archaeol. Sci. Rep. 11, 370–380. https://doi.org/10.1016/j.jasrep.2016.12.012.

Ambrose, S.H., 1990. Preparation and characterisation of bone and tooth collagen for isotopic analysis. J. Archaeol. Sci. 17, 431–451. https://doi.org/10.1016/0305-4403(90)90007-R.

Allsworth-Jones, P., 2004. The Szeletian revisited. Anthropologie. 3, 281–296.

Allsworth-Jones, P., 1986. The Szeletian and the Transition from Middle to Upper Palaeolithic in Central Europe. Clarendon Press, Oxford.

Arppe, L., Karhu, J.A., 2010. Oxygen isotope values of precipitation and the thermal climate in Europe during the middle to late Weichselian ice age. Quat. Sci. Rev. 29 (9–10), 1263–1275. https://doi.org/10.1016/j.quascirev.2010.02.013.

Baca, M., Mackiewicz, P., Stankovic, A., Popović, D., Stefaniak, K., Czarnogórska, K., Nadachowski, A., Gąsiorowski, M., Hercman, H., Węgleński, P., 2014. Ancient DNA and dating of cave bear remains from Niedźwiedzia Cave suggest early appearance of Ursus ingressus in Sudetes. Quat. Int. 339–340, 217–223. https://doi.org/10.1016/j.quaint.2013.08.033.

Baca, M., Popović, D., Stefaniak, K., Marciszak, A., Urbanowski, M., Nadachowski, A., Maciekwicz, P., 2016. Retreat and extinction of the Late Pleistocene cave bear (Ursus spelaeus sensu lato). Sci. Nat. 103 (11–12), 92. https://doi.org/10.1007/s00114-016-1414-8.

Baca, M., Stankovic, A., Stefaniak, K., Marciszak, A., Hofreiter, M., Nadachowski, A., Węgleński, P., Mackiewicz, P., 2012. Genetic analysis of cave bear specimens from Niedźwiedzia Cave, Sudetes, Poland. Palaeonto.l Electron. 15 (2), 21A.

Beresford-Jones, D.G., Johnson, K., Pullen, A.G., Pryor, A.J.E., Svoboda, J., Jones, M.K., 2010. Burning wood or burning bone? A reconsideration of flotation evidence from Upper Palaeolithic (Gravettian) sites in the Moravian Corridor. J. Archaeol. Sci. 37, 2799–2811. https://doi.org/10.1016/j.jas.2010.06.014.

Berto, C., Krajcarz, M.T., Moskal-del Hoyo, M., Komar, M., Sinet-Mathiot, V., Zarecka-Szubińska, K., Krajcarz, M., Szymanek, M., Wertz, K., Marciszak, A., Mętrak, M., Suska-Malawska, M., Wilcke, A., Kot, M., 2021. Environment changes during Middle to Upper Palaeolithic transition in Central Europe. A multiproxy approach for the MIS 3 sequence of Koziarnia Cave (Kraków-Częstochowa Upland, Poland). J. Archaeol. Sci. Rep. 35, 102723 https://doi.org/10.1016/j.jasrep.2020.102723.

Bobak, D., Płonka, T., Połtowicz-Bobak, M., Wiśniewski, A., 2013. New chronological data for Weichselian sites from Poland and their implications for Palaeolithic. Quat. Int. 296, 23–36. https://doi.org/10.1016/j.quaint.2012.12.001.

Brock, F., Higham, T., 2010. Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). Radiocarbon 52 (1), 103–112. https://doi.org/10.1017/S0033822200045069.

Bronk Ramsey, Christopher, 2017. Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59 (2), 1809–1833.

Bronk Ramsey, C., Higham, T.F.G., Leach, P., 2004. Towards high-precision AMS: Progress and limitations. Radiocarbon 46 (1), 17–24. https://doi.org/10.1017/S0033822200039308.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337–360. https://doi.org/10.1017/S0033822200033865.

Bronk Ramsey, C., Scott, M., van der Plicht, H., 2013. Calibration for Archaeological and Environmental Terrestrial Samples in the Time Range 26–50 ka cal BP. Radiocarbon 55 (4), 2021–2027. https://doi.org/10.2458/azu_js_rc.55.16935.

Buckley, M., Collins, M., Thomas-Oates, J., Wilson, J.C., 2009. Species identification by analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry. Rapid Commun. Mass Spectrom. 23 (23), 3843–3854. https://doi.org/10.1002/rcm.4316.

Buckley, M., Wadsworth, C., 2014. Proteome degradation in ancient bone: Diagenesis and phylogenetic potential. Palaeogeogr. Palaeoclimatol. Palaeoecol. 416, 69–79.

Chmielewski, W., 1961. Civilisation de Jerzmanowice. Zakład Narodowy im, Ossolińskich, Wrocław-Warszawa-Kraków.

Chmielewski, W., 1975. Prehistoria Ziem Polskich. Ossolińskich; Wrocław, Zakład Narodowy im.

Chmielewski, W., Kowalski, K., Madeyska-Niklewska, T., Sych, L., 1967. Wyniki badań osadów jaskini Koziarni w Sąsowie pow. Olkusz, Folia Quat, p. 26.

Cichocki, O., Knibbe, B., Tillich, I., 2014. Archaeological significance of the Palaeolithic charcoal assemblage from Krems-Wachtberg. Quat. Int. 351, 163–171. https://doi.org/10.1016/j.quaint.2013.07.004.

Cooper, A., Turney, C., Hughen, K.A., Brook, B.W., McDonald, H.G., Bradshaw, C.J., 2015. Abrupt warming events drove Late Pleistocene Holarctic megafaunal turnover. Science. 349 (6248), 602–606. https://doi.org/10.1126/science.aac4315.

Davies, W., White, D., Lewis, M., Stringer, C., 2015. Evaluating the transitional mosaic: Frameworks of change from Neanderthals to Homo sapiens in eastern Europe. Quat. Sci. Rev. 118, 211–242. https://doi.org/10.1016/j.quascirev.2014.12.003.

Demidenko, Y., Škrdla, P., Nejman, B., 2017. Aurignacian in Moravia. New geochronological, lithic and settlement data. Památky Archeologické 108, 5–38.

DeNiro, M.J., 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nature. 317, 806–809.

Desbrosse, R., Kozłowski, J.K., 1988. Hommes et climats a' l'âge du mammouth: Le Palèolithique supèrieur d'Eurasie centrale. Masson, Paris.

Dobosi, V.T., 2002. Bone finds from Istállóskő Cave. Praehistoria 3, 79–102.

Flas, D., 2011. The Middle to Upper Paleolithic transition in Northern Europe: The Lincombian-Ranisian-Jerzmanowician and the issue of acculturation of the last Neanderthals. World Archaeol. 43 (4), 605–627. https://doi.org/10.1080/00438243.2011.624725.

Flas, D., 2012. Jerzmanowice points from Spy and the issue of the Lincombian-Ranisian-Jerzmanowician. Anthropol. Praehist. 123 (1), 217–230.

Goslar, T., Czernik, J., Goslar, E., 2004. Low-energy 14C AMS in Poznań Radiocarbon Laboratory. Poland. Nucl. Instrum. Methods Phys. Res. 223, 5–11. https://doi.org/10.1016/j.nimb.2004.04.005.

Greguss, P., 1955. Xylotomische Bestimmung der heute lebenden Gymnospermen. Akadémiai Kiadó, Budapest.

Hercman, H., Szczerba, M., Zawidzki, P., Trojan, A., 2019. Carbon isotopes in wood combustion/pyrolysis products: Experimental and molecular simulation approaches. Geochronometria. 46, 111–124. https://doi.org/10.1515/geochr-2015-0110.

Higham, T.F.G., Compton, T., Stringer, C., Jacobi, R., Shapiro, B., Trinkaus, E., Chandler, B., Gröning, F., Collins, C., Hillson, S., O'Higgins, P., FitzGerald, C., Fagan, M., 2011. The earliest evidence for anatomically modern humans in northwestern Europe. Nature. 479, 521–524. https://doi.org/10.1038/nature10484.

Higham, T., Douka, K., Wood, R., Bronk Ramsey, C., Brock, F., Basell, L., Camps, M., Arrizabalaga, A., Baena, J., Barroso-Ruíz, C., Bergman, C.h., Boitard, C., Boscato, P., Caparrós, M., Conard, N.J., Draily, C.h., Froment, A., Galván, B., Gambassini, P., Garcia-Moreno, A., Grimaldi, S., Haesaerts, P., Holt, B., Iriarte-Chiapusso, M.-J., Jelinek, A., Jordá Pardo, J.F., Maíllo-Fernández, J.-M., Marom, A., Hoffecker, J.F., 2009. The spread of modern humans in Europe. PNAS 106 (38), 16040–16045. https://doi.org/10.1073/pnas.0903446106.

Hillebrand, J., 1910. A pleistocaen ösember ujabb nyomai hazánkban (Neure Spuren de diluvialen Menschen in Ungarn). Barlangkutatás I, 19–52.

Housley, R., 2003. Radiocarbon dating. In: Valde-Nowak P, Nadachowski A, Madeyska T, editors. Obłazowa Cave. Human activity, stratigraphy and palaeoenvironment. Instytut Archeologii i Etnologii PAN, Kraków, pp. 81-85.

Hoffecker, John F., 2009. The spread of modern humans in Europe. PNAS 106 (38), 16040–16045. https://doi.org/10.1073/pnas.0903446106.

Hublin, J.J., 2015. The modern human colonisation of western Eurasia: When and where? Quat. Sci. Rev. 118, 194–210. https://doi.org/10.1016/j.quascirev.2014.08.011.

Hublin, J.J., Bailey, S.E., 2006. Revisiting the Last Neanderthals. In: Conrad, N.J. (Ed.), When Neanderthals and Modern Humans Met. Kerns Verlag, Tübingen, pp. 105–128.

Hülle, W., 1939. Vorläufige Mitteilung über die altsteinzeitlidie Fundstelle Ilsenhöhle unter Burg Ranis, Kreis Ziegenrück. In: Andree, J. (Ed.), Der Eiszeitliche Mensch in Deutschland und seine Kulturen. F. Enke, Stuttgart, pp. 105–114.

Jacobi, R., 2007. A collection of Early Upper Palaeolithic artefacts from Beedings, near Pulborough, West Sussex and the context of similar finds from British Isles. Proc. Prehist. Soc. 73, 229–325. https://doi.org/10.1017/S0079497X00000098.

Jöris, O., Street, M., Terberger, T., Weninger, B., 2011. Radiocarbon Dating the Middle to Upper Palaeolithic Transition: The Demise of the Last Neanderthals and the First Appearance of Anatomically Modern Humans in Europe. in: Condemi, S., Weniger, G.C., (Eds.), Continuity and Discontinuity in the Peopling of Europe: One Hundred Fifty Years of Neanderthal Study: Proceedings of the international congress to commemorate "150 years of Neanderthal discoveries, 1856-2006". Springer, Bonn, pp. 239-298.

Kaminská, L., Kozłowski, J.K., Svoboda, J.A., 2004. The 2002–2003 excavation in the Dzeravá skala Cave, West Slovakia. Anthropologie. XLII/3, 311–322.

Kaminská, L., Kozłowski, J.K., Svoboda, J.A., 2005. Pleistocene Environments and Archaeology of the Dzeravá skala Cave, Lesser Carpathians. Slovakia, Kraków.

Kirby, D.P., Buckley, M., Promise, E., Trauger, S.A., Holdcraft, T.R., 2013. Identification of collagen-based materials in cultural heritage. Analyst. 138, 4849–4858. https://doi.org/10.1039/c3an00925d.

Kot, M., Gryczewska, N., Berto, C., Wojenka, M., Szeliga, M., Jaskulska, E., Fetner, R., Krajcarz, M., Wertz, K., Zarzecka-Szubińska, K., Krajcarz, M.T., Moskal-del Hoyo, M., Jakubczak, M., 2019a. Thirteen cave sites: Settlement patterns in Sąspów Valley, Polish Jura. Antiquity. 2019; 93(371), e30. 10.15184/aqy.2019.155.

Kot, M., Gryczewska, N., Biard, M., 2021. When the Leafpoints are Missing: On the Possibility of Identifying of Jerzmanowician Assemblages based on the Small Debitage Alone. Lithic Technology. https://doi.org/10.1080/01977261.2021.1880735.

Kot, M., Wojenka, M., Szeliga, M., 2019. Badania wykopaliskowe Stefana Krukowskiego w Dolinie Sąspowskiej. Wiad. Archeol. LXX, 51–78.

Kowalski, S., 1967. Wstępne wyniki badań archeologicznych w Jaskini Mamutowej prowadzonych w latach 1957–1964. Mater. Archeol. 8, 47–54.

Kowalski, S., 1969. Nowe dane do poznania kultury jerzmanowickiej w Polsce. Światowit 30, 177–188.

Kowalski, K., Kozłowski, J.K., Krysowska, M., Wiktor, A., 1965. Badania osadów w Puchaczej Skale w Prądniku Czajowskim, pow. Olkusz. Folia Quat. 20, 1–44.

Kozłowski, J.K., 2002. La grande plaine de l'Europe avant le Tardiglaciare. ERAUL. 99, 53–65.

Kozłowski, J.K., Kozłowski, S.K., 1996. Le Paléolithique en Pologne. Jérôme Million, Grenoble.

Kozłowski, J.K., Sobczyk, K., 1987. The Upper Palaeolithic Site Krakow-Spadzista Street C2, Excavations 1980. PWN, Warszawa-Kraków.

Kozłowski, L., 1922. Starsza Epoka Kamienia w Polsce (Paleolit). Poznańskie Towarzystwo Przyjaciół Nauk Prace Komisji Archeologicznej I(I) ,Poznań.

Kozłowski, S.K., 2007. Stefan Krukowski. Narodziny giganta. Warszawa: Państwowe Muzeum Archaeologiczne, Stowarzyszenie Naukowe Archaeologów Polskich, Warszawa.

Krajcarz, M.T., Cyrek, K., Krajcarz, M., Mroczek, P., Sudoł, M., Szymanek, M., Tomek, T., Madeyska, T., 2016. Loess in a cave - Lithostratigraphic and correlative value of loess and loess-like layers in caves from the Kraków-Częstochowa Upland (Poland). Quat. Int. 399, 13–30. https://doi.org/10.1016/j.quaint.2015.08.069.

Krajcarz, M.T., Krajcarz, M., Ginter, B., Goslar, T., Wojtal, P., 2018. Towards a Chronology of the Jerzmanowician—a New Series of Radiocarbon Dates from Nietoperzowa Cave (Poland). Archaeometry 60, 383–401. https://doi.org/10.1111/arcm.12311.

Krajcarz, M.T., Sudoł, M., Krajcarz, M., Cyrek, K., 2012. The site of Late Quaternary cave sediments - The Shelter above the Zegar Cave in Zegarowe Rocks (Częstochowa Upland). Prz. Geol. 60, 546–553.

Lorenc, M., 2006. Radiocarbon dating of some Late Pleistocene faunal assemblages in caves in Poland. Acta Zool. Cracov. 49A (1–2), 41–61. https://doi.org/10.3409/000000006783995508.

Lorenc, M., 2013. Radiocarbon ages of bones from Vistulian (Weichselian) cave deposits in Poland and their stratigraphy. Acta. Geol. Pol. 63 (3), 399–424. https://doi.org/10.2478/agp−2013−0017.

Mackiewicz, P., Baca, M., Popović, D., Socha, P., Stefaniak, K., Marciszak, A., Nadachowski, A., 2017. Estimating the extinction time of two cave bears. Acta. Zool. Cracov. 60 (2), 1–14. https://doi.org/10.3409/azc.60_2.01.

Madeyska-Niklewska, T., 1969. Górnoplejstoceńskie osady jaskiń Wyżyny Krakowskiej. Acta Geol. Pol. 19 (2), 341–392.

Madeyska, T., 1992. Stratigraphy of the sediments in the Mamutowa Cave at Wierzchowie near Cracow. Folia Quat. 63, 35–42.

Markó, A., 2015. Istállóskő revisited: lithic artefacts and assemblages, sixty years after. Acta Arch. Hung. 66, 6–38. https://doi.org/10.1556/072.2015.66.1.1.

Markó, A., 2017. Istállóskő revisited: The osseous artefacts from the lower layer. Acta Archaeol. Acad. Sci. Hungaricae. 68 (2), 193–218. https://doi.org/10.1556/072.2017.68.2.1.

Moskal-del Hoyo, M., Kozłowski, J.K., 2009. Botanical identification of wood charcoal remains and radiocarbon dating – new examples of the importance of taxonomical identifications prior to 14C dating. Spraw. Archeol. 61, 253–271.

Nadachowski, A., Lipecki, G., Wojtal, P., Miękina, B., 2011. Radiocarbon chronology of woolly mammoth (Mammuthus primigenius) from Poland. Quat. Int. 245, 186–192. https://doi.org/10.1016/j.quaint.2011.03.011.

Neruda, P., Nerudová, Z., 2013. The Middle-Upper Palaeolithic transition in Moravia in the context of the Middle Danube region. Quat. Int. 294 (C), 3–19. https://doi.org/10.1016/j.quaint.2011.08.035.

Nowak, M., Moskal-del Hoyo, M., Mueller-Bieniek, A., Lityńska-Zając, M., Kotynia, K., 2017. Benefits and weaknesses of radiocarbon dating of plant material as reflected by Neolithic archaeological sites from Poland, Slovakia and Hungary. Geochronometria. 44, 188–201. https://doi.org/10.1515/geochr-2015-0066.

Pettitt, P., 2004. Radiocarbon age of the Early Aurignacian at Piekary II. In: Sachse-Kozłowska, E., Kozłowski, S.K. (Eds.), Piekary près de Cracovie (Pologne) complexe de sites Paléolithiques. Polska Akademia Umiejętności, Kraków, p. 301.

Połtowicz-Bobak, M., Bobak, D., Badura, J., Wacnik, A., Cywa, K., 2013. Les nouvelles données sur le Szélétien en Pologne. in: Bodu, P., Chehmana, L., Klaric, L., Mevel, L., Soriano, S., Teyssandier, N. (Eds.), Le Paléolithique supérieur ancien de l'Europe du Nord-Ouest: Réflexions et synthèses à partir d'un projet collectif de recherche sur le centre et le sud du Bassin parisien – Actes du colloque de Sens; 2009 Apr 15-18, Mémoires de la Société préhistorique française. 56: 485-496.

Pope, M., Dinnis, R., Milks, A., Toms, P., Wells, C., 2013. A Middle Palaeolithic to Early Upper Palaeolithicsuccession from an open air site at Beedings, West Sussex. Quat. Int. 316, 14–26. https://doi.org/10.1016/j.quaint.2013.06.027.

Ralska-Jasiewiczowa, M., Latałowa, M., Wasylikowa, K., Tobolski, K., Madeyska, E., Wright Jr., H.E., Turner, T., 2004. Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Science, Kraków, Kraków.

Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Buchardt, S.L., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsena, S.J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J.J., Pedro, J.B., Popp, T., Seierstad, I.K., Steffensen, J.P., Svensson, A.M., Vallelonga, P., Vinther, B.M., Walker, M.J., Wheatley, J.J., Winstrup, M., 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronised Greenland ice-core records: Refining and extending the INTIMATE event stratigraphy. Quat Sci Rev. 106, 14–28.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C.H., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. Radiocarbon 55 (4), 1869–1887. https://doi.org/10.2458/azu_js_rc.55.16947.

Römer, F., 1883. Die Knochenhöhlen von Ojcow in Polen. Palaeontographica 29, 193–233.

Römer, F., 1884. Bone-caves of Ojców in Poland. Translated by J.E.Lee, Longmans, Green and CO, London.

Sachse-Kozłowska, E., 1978. Polish Aurignacian assemblages. Folia Quat. 50, 1–49.

Schweingruber, F.H., 1990. Anatomie Europäischer Hölzer. Paul Haupt Berne und Stuttgart Publishers, Bern-Stuttgart.

Seierstad, I.K., Abbott, P.M., Bigler, M., Blunier, T., Bourne, A.J., Brook, E., Buchardt, S. L., Buizert, C.h., Clausen, H.B., Cook, E., Dahl-Jensen, D., Davies, S.M., Guillevic, M., Johnsen, S.J., Pedersen, D.S., Popp, T.J., Rasmussen, S.O., Severinghaus, J.P., Svensson, A., Vinther, B.M., 2014. Consistently dated records from the Greenland GRIP, GISP2 and NGRIP ice cores for the past 104 ka reveal regional millennial-scale δ18O gradients with possible Heinrich event imprint. Quat. Sci. Rev. 106, 29–46. https://doi.org/10.1016/j.quascirev.2014.10.032.

Straus, L.G., 2009. Has the Notion of "Transitions'' in Paleolithic Prehistory Outlived Its Usefulness? The European Record in Wider Context. in: Camps, M., Chauhan, P. (Eds.), Sourcebook of Paleolithic Transitions. Methods, Theories, and Interpretations. Springer, London, pp. 3-18.

Svoboda, J.A., 2001. La question szélétienne. in: Cliquet, D. (Ed.), Les industries à outils bifaciaux du Paléolithique moyen d'Europe occidentale. Actes de la table-ronde internationale organisée à Caen (Basse-Normandie - France); 1999 Oct 14-15; Caen, France. Liège: Université de Liège, ERAUL. 2001;98. p. 221-30.

Svoboda, J.A., 2004. Continuities, discontinuities and interactions in Early Upper Paleolithic technologies. In: Brantingham, P.J., Kuhn, S.L., Kerry, K.W. (Eds.), The Early Upper Paleolithic beyond Western Europe. University of California Press, Berkeley, pp. 30–49.

Svoboda, J.A., Hladilova, Š., Horaček, I., Kaiser, J., Králík, M., Novák, J., Novák, M., Pokorný, S.S., Smolíková, L., Zikmund, T., 2015. Dolní Vestonice IIa: Gravettian microstratigraphy, environment, and the origin of baked clay production in Moravia. Quat. Int. 359, 195–210. https://doi.org/10.1016/j.quaint.2014.06.048.

Terlato, G., Bocherens, H., Romandini, M., Nannini, N., Hobson, K.A., Peresani, M., 2019. Chronological and Isotopic data support a revision for the timing of cave bear extinction in Mediterranean Europe. Hist Biol. 31 (4), 474–484. https://doi.org/10.1080/08912963.2018.1448395.

Tostevin, G.B., 2013. Seeing Lithics: A Middle-Range Theory for Testing for Cultural Transmission in the Pleistocene. Oxbow Books, Cambridge.

Valde-Nowak, P., Nadachowski, A., Madeyska, T., 2003. Obłazowa Cave: Human Activity, Stratigraphy, and Palaeoenvironment. Institute of Archaeology and Ethnology Polish Academy of Sciences, Krakow.

Valladas, H., Mercier, N., Escutenaire, C., Kalickim, T., Kozłowski, J.K., Sitlivy, V., Sobczyk, K., Zięḑba, A., van Viliet-Lanoë, B., 2003. The Late Middle Palaeolithic Blade Technologies and the Transition to the Upper Palaeolithic in Southern Poland: TL Dating Contribution. Eurasian Prehist. 1 (1), 57–82.

Valladas, H., Mercier, N., Froget, L., Joron, J.L., Reyss, J.-L., Kaltnecker, E., Tisnerat, N., Fifield, L.K., 2008. Radiometric dates for the Middle Palaeolithic sequence of Piekary. In: Sitlivy, V., Zięba, A., Sobczyk, K. (Eds.), Middle and Early Upper Palaeolithic of the Krakow Region Piekary IIa. Royal Museum of Art and History, Brussels, pp. 49–56.

Valoch, K., 2000. More on the question of Neanderthal acculturation in Central Europe. Curr Anthropol. 41 (4), 625–626.

Van Doorn, N.L., Hollund, H., Collins, M.J., 2011. A novel and non-destructive approach for ZooMS analysis: Ammonium bicarbonate buffer extraction. Arch. Anthropol. Sci. 3 (3), 281–289.

Villa, P., Pollarolo, L., Conforti, J., Marra, F., Biagioni, C., Degano, I., Lucejko, J.J., Tozzi, C., Pennacchioni, M., Zanchetta, G., Nicosia, C., Martini, M., Sibilia, E., Panzeri, L., 2018. From Neandertals to modern humans: New data on the Uluzzian. PLoS ONE. 13 (5), e0196786 https://doi.org/10.1371/journal.pone.0196786.

Welker, F., Hajdinjak, M., Talamo, S., Jaouen, K., Dannemann, M., David, F., Julien, M., Meyer, M., Kelso, J., Barnes, I., Brace, S., Kamminga, P., Fischer, R., Kessler, B.M., Stewart, J.R., Pääbo, S., Collins, M.J, Hublin, J.J., 2016. Palaeoproteomic evidence identifies archaic hominins associated with the Châtelperronian at the Grotte du Renne. PNAS 2016 Oct 4. 2016; 113(40): 11162-11167. 10.1073/pnas.1605834113.

White, R.K., 1982. Rethinking the Middle/Upper Paleolithic transition. Curr. Anthropol. 23 (2), 169–176. https://doi.org/10.1086/202802.

Wilczyński, J., 2015. The Jaksice II site – History of research. In: Wilczyński, J. (Ed.), A Gravettian Site in Southern Poland: Jaksice II. Institute of Systematics and Evolution of Animals, Polish Academy of Sciences Kraków, pp. 3–14.

Wilczyński, J., Miękina, B., Lipecki, G., Lõugas, L., Marciszak, A., Rzebik-Kowalska, B., Stworzewicz, E., Szyndlar, Z., Wertz, K., 2012a. Faunal remains from Borsuka Cave.

An example of local climate variability during Late Pleistocene in southern Poland. Acta Zool. Cracov. 52 (2), 131–155. https://doi.org/10.3409/azc.55_2.131.

Wilczyński, J., Wojtal, P., Sobczyk, K., 2012b. Spatial organization of the Gravettian mammoth hunters site - Kraków Spadzista (southern Poland). J. Archaeol. Sci. 39, 3627–3642. https://doi.org/10.1016/j.jas.2012.05.012.

Wilczyński, J., Wojtal, P., Sobieraj, D., Sobczyk, K., 2015. Kraków Spadzista trench C2 - new research and interpretations of Gravettian settlement. Quat. Int. 359–360, 96–113. https://doi.org/10.1016/j.quaint.2014.08.025.

Wilczyński, J., Žaár, O., Nemergut, A., Kufel-Diakowska, B., Moskal-del Hoyo, M., Mroczek, P., Páll-Gergely, B., Oberc, T., Lengyel, G., 2020. The Upper Palaeolithic at Trenčianske Bohuslavice, Western Carpathians. Slovakia. J. Field. Archaeol. 45 (4), 270–292. https://doi.org/10.1080/00934690.2020.1733334.

Wiśniewski, A., Płonka, T., Jary, Z., Lisa, L., Traczyk, A., Kufel-Diakowska, B., Raczyk, J., Bajer, A., 2015. The early Gravettian in a marginal area: New evidence from SW Poland. Quat. Int. 359–360, 131–152. https://doi.org/10.1016/j.quaint.2014.10.003.

Wojtal, P., 2007. Zooarchaeological Studies of the Late Pleistocene Sites in Poland. Institute of Systematics and Evolution of Animals Polish Academy of Sciences, Kraków.

Wojtal, P., Sobczyk, K., 2003. Taphonomy of the Gravettian site – Kraków Spadzista Street (B), in: Reumer, J.W.F., De Vos, J., Mol, D. (Eds.), Advances in Mammoth Research: Proceedings of the Second International Mammoth Conference; 1999 May 16-20; Rotterdam, Holandia. DEINSEA. 9, 557-62.

Wojtal, P., Sobczyk, K., 2005. Man and woolly mammoth at the Kraków Spadzista Street. Street (B) taphonomy of the site. J. Archaeol. Sci. 32, 193–206. https://doi.org/10.1016/j.jas.2004.08.005.

Wojtal, P., Wilczyński, J., Nadachowski, A., 2015. Münzel SC. Gravettian hunting and exploitation of bears in Central Europe. Quat. Int. 359–360, 58–71. https://doi.org/10.1016/j.quaint.2014.10.017.

Zawisza, J., 1882a. Poszukiwania w Jaskini Mamuta 1877 i 1878. Wiad. Archeol. 4, 1–16.

Zawisza, J., 1882b. Dokończenie poszukiwań w Jaskini Mamuta 1879 r. Wiad. Archeol. 4, 16–18.

Zilhão J., 2013. Neandertal-Modern human contact in Western Eurasia: Issues of dating, Taxonomy, and Cultural Associations. in: Akazawa, T., Nishiaki, Y., Kenichi, A. (Eds.), Dynamics of Learning in Neanderthals and Modern Humans Vol. 1: Cultural Perspectives, Replacement of Neanderthals by Modern Humans Series. Springer, Japan, pp. 21–57.